REPORT RESUMES

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THE COMPUTER IN PHYSICS INSTRUCTION, REPORT OF THE CONFERENCE ON USES OF THE COMPUTER IN UNDERGRADUATE PHYSICS INSTRUCTION (UNIVERSITY OF CALIFORNIA, IRVINE, NOVEMBER 4-6, 1966).
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THE ROLE OF THE COMPUTER IN UNDERGRADUATE PHYSICS INSTRUCTION IS PRESENTED. MAJOR TOPICS INCLUDED IN THE REPORT ARE CURRICULAR ADMINISTRATIVE PROBLEMS, PEDAGOGICAL TECHNIQUES, AND SYSTEMS AND EQUIPMENT. INFORMATION RELATED TO LINGUISTICS MODE COMPUTER SYSTEMS, REMOTE CONSOLE EQUIPMENT, LINGUISTICS MODE PHYSICS PROGRAMS, COMPUTATIONAL MODE PHYSICS PROGRAMS, AND COMPUTATIONAL MODE COMPUTER LANGUAGES ARE INCLUDED IN THE REPORT. SEVERAL EXISTING UNIVERSITY COMPUTER-ASSISTED LEARNING SYSTEMS AND PROGRAMS ARE DESCRIBED. (AG)

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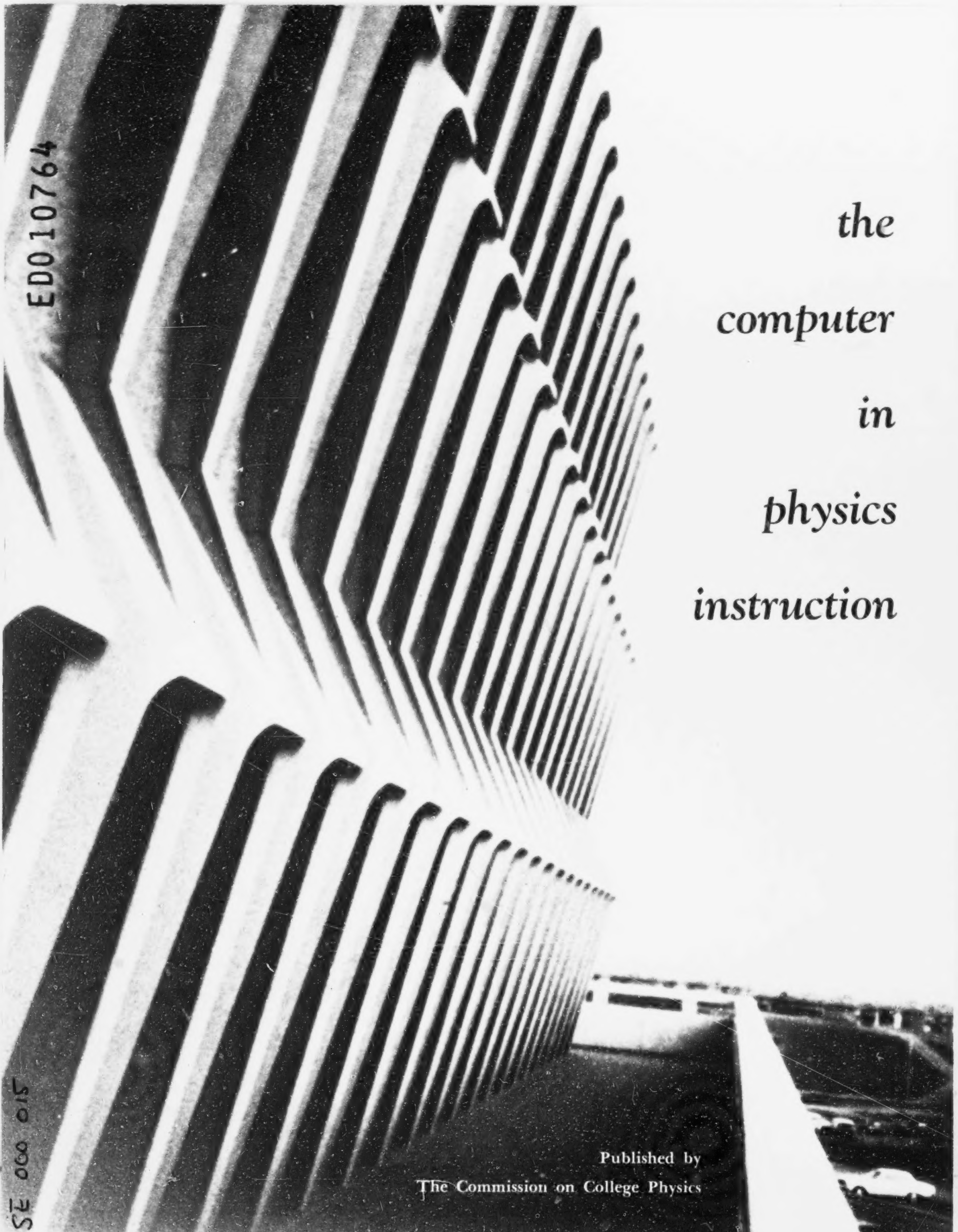

the
computer
in
physics
instruction

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COVER PHOTO: View of the Natural Sciences Building at the University of California, Irvine, which houses the Physics Department and in which several of the Conference meetings took place. Photo by John M. Fowler.

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the computer in physics instruction

Report of the Conference on the Uses of the Computer
in Undergraduate Physics Instruction
held
November 4–6, 1965
at
The University of California
Irvine

Sponsored by The Commission on College Physics

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preface

Topical conferences in physics are usually called after major advances have been made. When the planning began for the Conference on the Uses of the Computer in Undergraduate Physics Instruction, however, there were no advances to consider. The computer had found use in a few physics classrooms, but in an obvious extension of its research role, as a computational tool which increased the range of problems accessible to student solution.

There were, and are, however, problems other than those in physics which face the instructor. There is a national pattern of increasing student enrollment and decreasing faculty time which is particularly evident in the large introductory courses. And there is an increasing number of students who would benefit from more individualized assistance of a rather routine sort; students who, lacking this help, now pass out of further serious interest in physics.

In the experimental CAI[1] programs which exist elsewhere, and in the vision seen by computer pioneers, there is the promise of help with these larger problems. It was on this promise that the Conference was based.

The idea for the conference grew from discussions between Alfred Bork and Kenneth Ford in the fall of 1964. Ford and Bork had both had an introduction to the educational possibilities of the computer. Ford, at Irvine, had been exposed to the enthusiasm of those who planned a major fusion of technology and instruction at this new university. Bork had gained considerable experience with classroom and laboratory use of computer programs. Both felt the need to bring interested physicists together with computer pioneers.

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[1] Computer-Assisted Instruction (CAI) has become a common appellation. In this report, to emphasize our view that instruction in this way will not be the single or even the dominant mode in physics and to underscore the self-instructional features of our suggestions, we are using the acronym CAL, Computer-Assisted Learning. This also serves to honor the host state for our conference.

Leonard Jossem and the Commission on College Physics entered the discussions in the spring of 1965 and by that summer several physicists were putting together the first, necessarily crude, teaching dialogues at Seattle.[2] By the end of that summer the Conference had a goal, a place, a time, and a list of invitees.

The goal was ambitious: to prepare a comprehensive report—a handbook—which would be immediately useful to the physicist who was interested in the computer's instructional possibilities. It was to contain a discussion of the pedagogical tasks presently feasible for the computer, to foresee the curricular–administrative problems its introduction would raise, and to catalog the available and pertinent equipment.

As a place, Irvine was a natural choice. It had installed its computer and student terminals almost before its students. Its dean, Ralph Gerard, is an enthusiastic herald of the computer's role in education, and Kenneth Ford is the chairman of the physics department.

The time, November 1965, seemed right too: It was after the first trials at Seattle; it was a year before the expected delivery of the first big time–sharing systems and at least two years before any real possibilities of widespread classroom testing. In fact, however, it was almost too late. Computer technology develops rapidly and report writing is slow.

The list of invitees was easily drawn up. First, all of the physicists known to have dabbled in this new medium or expressed some desire to do so were invited. To this list was added an approximately equal number of computer experts either caught between conferences, resident on the West Coast, or just generous enough to help the physicists out. We then let the computer–related industries know of our plans and urged that they be represented.

The Conference was a working conference. Its structure was simple. The first day was for input; the second day, assembly and writing; and the third, review. The speakers at the opening session were E. N. Adams,[3] who surveyed the role of the computer in instruction; Joseph Rosenbaum,[4] who described four experimental instructional computer programs; and Glen Culler,[5] who previewed an intriguingly simple remote terminal with enormous computational possibilities. (This was demonstrated later in the Conference.) A slightly condensed version of Adams' talk serves to introduce this Report. Rosenbaum's remarks, in abstracted form, make up Appendix D, and Culler's talk, together with a sample problem solved by his system, is given in Appendix F.

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[2] Working Conference on New Instructional Materials held at the University of Washington during the summer of 1965.

[3] Director, Computer–Assisted Instruction, IBM Instructional Systems Development, Watson Research Center.

[4] Education and Training Staff, System Development Corporation.

[5] Director, Computer Center, University of California, Santa Barbara.

The afternoon was given over to the industrial representatives who described the hardware and software now available, and gave us some glimpses of future lines of development.

Three working groups were convened the second day. The reports of these groups and the appendices which they called for form the bulk of this Report. The group surveying curricular–administrative problems was asked to be almost clairvoyant: it tried to foresee the operational development of the computer as a part of the instructional system in higher education. Their report will, we hope, help prepare the thoughtful physicist or administrator for the problems as well as the opportunities ahead.

The group on pedagogy and the group on systems and equipment had more narrow fields of study and a little more real material to examine. The pedagogy group had some guidelines from Seattle and the systems and equipment group had almost too many examples of hardware and software to classify and describe.

We have already come a long way from Irvine. Two program–writing activities will begin this summer—one at the MIT Science Teaching Center; one at Stony Brook. Students will, through several remote terminals at Stony Brook, already have signed onto the Seattle–developed geometrical optics unit (see Appendix C) this spring, providing the first large–scale student experience with CAL in physics.

It is our hope that this Report will serve usefully before its early obsolescence, that it will stimulate and assist further creative experimentation. Only by such experimentation can the problems which we anticipate be solved and the promise we foresee be realized.

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acknowledgments

Any conference report is a joint effort, but in the preparation of this report, the CCP staff has had to rely even more than usual on outside assistance. The list of acknowledgments is thus a long one, longer for certain than the list of participants that it must include.

We wish to make a special acknowledgment to the working group chairmen—Donald R. Brown, Edward D. Lambe, and Burton D. Fried—for their help before, during and after the Conference. Karl Zinn (The University of Michigan) contributed much of the material for the appendices on equipment and existing CAL systems; his careful reading of the technical material and his suggestions have helped to make these sections accurate and comprehensive.

We also express our appreciation to the following people who either contributed written material to the report, provided necessary data, and/or read and commented on parts of the report: E. N. Adams (IBM Watson Research Center), Alfred M. Bork (Reed College), Ralph Caplan, Glen J. Culler (University of California, Santa Barbara), Joseph Rosenbaum (System Development Corporation), Donald Shirer (Valparaiso University), Franklin H. Westervelt (The University of Michigan), William F. Storey (Michigan Bell Telephone Company), and numerous manufacturers' representatives who provided much of the information appearing in Appendix B.

We extend our thanks to Kenneth Ford and the administration of the University of California at Irvine for their smooth handling of local arrangements and pleasant performance of their duties as Conference host.

The selection of material and the final writing of all sections was done by John M. Fowler, Peter G. Roll, and Barbara Z. Bluestone of the CCP staff; we accept responsibility for whatever errors and/or omissions have occurred in the Report.

introduction

Roles of the Computer in University Instruction[1]

Much creative spadework and many detailed exploratory developments will have to be made before the full potential of the computer as an instructional tool can be exploited. This development must proceed in two directions. One of these is the creation of new technological tools with special value for educational use; the other is the development of an understanding of how these tools are to be used.

One purpose of this Conference is to point to important particular directions of such development where these directions can be recognized. Another is to indicate which applications of the computer to physics instruction may be most profitably pursued with techniques that are presently feasible. I believe that obtaining experience with the application of state-of-the-art technology may be the more important undertaking of the two in the immediate future; so little is yet established concerning the methodology of computer use in education that even a moderate amount of instructional experience seems capable of broadly affecting our perspective of what is needed and what will be important in the longer range future. In accordance with this belief the emphasis of my remarks will be on what seems feasible in the immediate future for operational exploration in an instructional environment.

I might begin by indicating the four main non-administrative areas of impact of the computer on the university program as they appear to me. The first role of the computer is as a vehicle for the computer-science discipline. . . .

A second role is as a general university service providing remote computing facilities . . . to time-share the services of a large high-speed central computer through a network of terminals . . . around the campus. . . .

A third role of great apparent future importance is as an essential component of the generalized library function . . . of storage, processing, and distribution of information . . . .

A fourth role of the computer is as an active element in the instructional process itself. This role we will refer to as computer assistance to instruction or CAI.[2] It is a complex role, involving the exploitation of several major subroles which I will refer to as "themes," because, although distinct in nature, several may be present concurrently in a particular application. The remainder of this paper will be concerned with a survey of these individual themes.

We will categorize the major themes in CAI as follows: (1) man-machine communication; (2) machine-administered recitation and drill; (3) the Ersatz laboratory; (4) recording and processing student performance; and (5) testing.

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[1] The following is a slight condensation of an invited speech delivered to the Conference by Dr. E. N. Adams, Director of Computer Assisted Instruction at IBM's Watson Research Center in Yorktown Heights. A complete transcript of this talk is available from Dr. Adams.

[2] As indicated in the preface, we have chosen to use the acronym CAL (Computer-Assisted Learning) rather than CAI throughout this Report [editor's note].

Man–Machine Communication

The importance of the first of these themes arises from the serious difficulties which are intrinsic in man–machine communication, and the corresponding benefits which may be realized by facilitating that communication through superior station equipment and communications capability. Basic to the communication process are both the physical organs of communication with the computer and, with each of these, the implied or associated logical capabilities of the computing system.

One of the most common means of getting information into and out of a computer is through the use of punched cards . . . . Much of the early work in CAI has been done using this off–line, slow–response communication means.

For a number of the potential instructional uses of the computer it is essential that the user be on–line; i.e., in direct and immediate communication with the machine in so–called "conversational mode." Commonly–used means for on–line communication of alphanumeric messages is an input–output typewriter, or a console consisting of a keyboard and a cathode ray tube display. For input messages which are not simply alphanumerical, various kinds of special keyboards or other switch–type selectors are feasible. For output a great variety of terminal configurations are also feasible using lights, fluorescent panels, etc. In addition, terminal configurations can readily be engineered to incorporate display capabilities such as randomly–accessed still pictures, audio recordings, moving film, and video tape.

Each piece of such terminal gear must have a suitable "interface unit" or "adapter" so that it can communicate with the computer in the appropriate machine language. As software, the computer must have within its repertoire of operation codes commands which permit it to control and to receive information from the terminal equipment . . . .

The utility of the system for instructional use is dependent in an important way on the capability of the computer to process linguistic information and also on the facility with which a system user (e.g., a physics teacher) can program the use of the processing capability. The first of these important matters is a question of what particular functional routines for message processing are available in the computer system program; the second is a question of the procedures for operating the system and of the programming language in which the user formulates his instructions.

The most elementary message–processing operation is the recognition of an input message as one of a group of prestored messages. Such a processing capability may suffice for applications in which the messages are always of a simple sort; for example, the selection of a single key of a keyboard or a single field of a keyboard. For many instructional purposes it is desirable to have the machine accept relatively complex messages, particularly messages in natural language. In such applications more extensive logical processing capability is needed. Some kind of editing is necessary to cope with the vagaries of keying and punctuation. Some at least rudimentary pattern recognition techniques may be desirable for estimating the similarity of non–identical messages. Very desirable for physics instruction is some ability to manipulate or at least evaluate mathematical functions.

As one goes beyond the requirement for exact match processing and progresses down the list from editing to formula manipulation, the complexity of program preparation and the requirements for program storage increase significantly. Moreover, on a per–terminal–serviced basis, the execution of more complex programs normally imposes a greater average load on the processor. Very elaborate processing requirements can prove excessively costly. Thus, it is prudent to try to stipulate processing requirements on the basis of a realistic assessment of tradeoff of total student load serviced against complexity of pedagogical function.

Programming language and operational features of the control program should be designed after careful consideration of the intended modes of instructional use and the convenience of the putative users . . . .

In addition to equipment which communicates with the computer by means of symbolic messages, there is terminal equipment which processes analogue messages. With such equipment it is technologically feasible to some significant extent to synthesize audio messages, to display data in the form of graphs and other synthesized video displays, to accept graphical or video input directly through electronic slates, light pens, optical scanners, or kinescopes, and similarly to accept audio and other analogue data directly as analogue messages . . . .

Finally, I will comment on the often–discussed possibilities of having computers directly translate voiced sound or graphical input to alphanumeric messages for subsequent processing. My judgment is that, although limited feasibility of such techniques has been demonstrated by various workers exploring this application, general use of such techniques as a principal and normal means of input is not yet close to practicability.

Machine-Administered Recitation and Drill

A second major instructional theme of CAI involves the direct machine administration of recitation and drill. Here the thrust of effort is to present programmed instructional sequences which use sophisticated algorithms of presentation and of response processing made possible by the logical and calculational capabilities of the computer. The mode of operation is basically one of individual student recitation, with the student communicating in conversational mode with the computing system and receiving tutorial commentary from the computer, according to a general program prepared by a tutorial programmer. . . .

Early "teaching machines" and programmed texts were characterized by relatively rigid, individually simple tasks, which were, for the most part, unchallenging and not very interesting. These characteristics are not intrinsic to programmed learning; they had their origin in the limited technology of student response processing which had until recently been available to the programmer. With a computer to administer a program of instruction, the programmer may avoid much of this rigidity and dullness. . . . Further, the computer may be programmed to arrange for continual adjustment of item difficulty or item pacing so that the student works at a predetermined level of interim and final achievement, avoiding extremes of either boredom or discouragement.

Given the capability through the computer to remember a student's past experience, to edit and analyze his response to a certain extent, and to take account of both present and past behavior in controlling program flow, a course programmer can now reasonably aspire to produce a program of instruction which has something of the quality of the interaction between a student and a human tutor. Instead of only a small-step task, he can present a complex, structured task as a sequence of non-trivial contingent decisions or actions, and he can work through it with the student in a tutorial manner. Such a capability would seem to be of relatively great importance in physics instruction, which does not seem suited to small-step programming.

The Ersatz Laboratory

The third theme of CAI I will call the "Ersatz laboratory." . . . I am not referring here to the use of CAI in association with laboratory equipment. It is clearly feasible to incorporate computer-assisted instruction into a traditional laboratory to a certain extent, possibly to a considerable extent. . . . By an Ersatz laboratory I mean something different; a laboratory without the usual kind of equipment, a kind of "substitute" laboratory, similar in use if not in substance to the traditional laboratory. Using CAI in such a laboratory mode, one may realize at least some of the value of well-conceived laboratory instruction in general: that of exercising, and hence developing in the student, the facility to carry through relatively complex tasks under his own initiative and with minimal supervision, and in that way learning by manipulating "reality" and observing the reactions. Of course, CAI in an Ersatz laboratory cannot replace some of the important values of traditional instruction in a traditional laboratory, and would not be satisfactory as more than a partial substitute for such instruction.

On the other hand the Ersatz laboratory has special advantages which may be understood by considering some examples of its realization. One example is the instruction in management techniques by means of a business game in which a player, or a team of players, operates an imaginary business in competition with either a predetermined performance criterion or with other imaginary businesses operated by other teams undergoing instruction. The players periodically make decisions of the sort involved in operational management; the results of their decisions are submitted to a computer simulator; the computer simulates the running of the hypothetical business environment for a period of time under the impact of these decisions; it reports back the business results at the end of the period; and finally, the players study reports of operating results and initiate another cycle. . . . In this laboratory the computer performs no direct tutorial service, but merely serves as an off-line calculational aid to quickly inform the students of the hypothetical consequences of their hypothetical business decisions.

A related example of such CAI laboratory instruction was encountered in a course in lens design for optical engineers. This course makes use of a computer service program which, to speak loosely, does repeated ray tracing calculations and calculates values for various merit figures of a hypothetical optical system, which is characterized to the computer program by the ordinary parameters of optical design. To use the program, the student lens designer chooses and enters the values of these parameters into the lens evaluation program; what he gets back are the computed quantities from which he can judge the quality of the resulting system for its desired purpose. By repeated running of this program a student engineer may explore the sensitivity of the performance of an optical system of interest to the various parameters of design. . . .

There is an advantage to the explicit presentation of the Ersatz lab as a means of exposition of theoretical models of reality: we can offer the students laboratory CAI programs which go quite far in the representation of the abstract. Clearly, a computer program can simulate processes operating over ranges of time, size, temperature, etc., which could never be realized in any single laboratory or even in any real laboratory. By manipulating the parameters of programs simulating these processes, a student can explore and get the "feel" of the physics in areas of physical reality which he must otherwise approach on a purely theoretical plane. . . .

Recording and Processing Student Performance

A fourth theme of CAI involves the monitoring, recording, itemizing, summarizing and analyzing of student behavior for a variety of purposes. I will enumerate three major purposes. One is the compilation and analysis of individual student performance data for tutorial, diagnostic, and remedial purposes. A second is the analysis and summary of statistical student performance data in accordance with characteristics of the course items themselves, with the object of improving the instructional material. A third purpose is behavioral research, which may concern itself with analyzing latencies of response, or a variety of physiological and/or environmental variables, in correlation with performance of various tasks. . . .

Testing

The fifth and final theme of my categorization is that of testing. There are several ways one may conceive of the computer as affecting the testing process. One is as a technical means of achieving controlled presentation of standardized tests. In addition to improvement of test administration, this use of the computer may be of special interest during the standardization phase of test preparation, where the difficulty of getting good control of presentation conditions can reflect itself in an apparent vitiation of the test items themselves.

A second potentiality is the very open-ended one of developing new test methods or testing techniques. Tutored testing, sequential testing, tests which have items which depend on student profiles, tests incorporating latencies and other physiological data—all of these become feasible in principle with the computer. . . .

In another direction, an enlarged diagnostic potential from testing may be realized through computer analysis of data obtained in conjunction with machine–administered recitation and drill. Thus, if all of the data from student performance on the recitation and drill were accumulated and properly analyzed as the input to a continuous examination, the data base for test analysis would be expanded enormously, and the potential diagnostic power of the test increased correspondingly. One yield from such testing could be improved measures of student achievement; another, and possibly more important, one could be that of continuing student classification and placement, a continuous "tailoring" of the student's curriculum to his evidenced needs.

State–of–the–Art CAI Research

The above survey should give a reasonable indication of the potential scope of computer aid to instruction. Let me present now some personal thoughts as to why it is relatively important at this time to do research by means of "state–of–the–art" instruction via CAI. I have been doing some of this research for several years, and have become very conscious of a number of major practical difficulties. My remarks will be directed to some of these difficulties on the assumption that wherever there are difficulties there are things to be learned.

. . . . In programming a CAI system, one must give appropriate thought to all those who are going to use it, which means not merely students, but also system operators, supervising teachers, supervising administrators, curriculum specialists, and behavioral research people. What may appear to be operational niceties for an experimental system turn out to be necessities when it comes to instructional evaluation: authors and especially students react strongly to "small" irritations which might *a priori* seem to be minor in comparison with the "big" problems. It is especially important to have programming languages and/or operational procedures which are really convenient for the various users, which do not demand too much of them and yet do a good deal for them.

Quite apart from the many detailed difficulties of designing a usable system, there is the problem of learning what to do with it. . . . In my judgment, this problem area is presently a crucial one in terms of accelerating the development of the field. Whereas it is commonly supposed that any problem of pedagogy will be disposed of by finding ways "to help the teachers talk to the engineers," I think the problem is harder than that. Any extensive use of the computer as an instructional tool in physics, for example, would permit—if not require—a substantial restructuring of the whole interlocking process of lectures, problem sessions, homework, quizzes, and laboratories, and a reapportionment of the various educational objectives among them. Perhaps the most essential step in designing a good program is that of thinking through how one would intend to do this restructuring.

Unfortunately, however, the programmer does not have any natural and well–defined frame of reference in which to rework the process: how the process is structured depends on what the machine is to do; what it is to do depends on what it can do; but what it can do is not fixed, nor is it immediately known to the "teacher–turned–programmer." If he didn't design the systems program of the machine, it almost certainly will not have all of the capabilities he would wish in a form convenient for his use. Some extensions of capability which he would desire may be had, so to speak, for the asking; on the other hand, others, which to the technically–naive person might seem similar, may actually be practically impossible to have. . . . Ideally, the pedagogical innovator should become enough of an engineer to understand in its essentials the work of those who are developing the machine capacities which he needs to accomplish his pedagogical task. He can then adjust his specification of the pedagogical task to facilitate the engineering work and the educational objective simultaneously.

Even where creative teachers and systems people have been able to devise what appear to be promising techniques and strategies of teaching in a particular area, they must continually test their ideas on learners. . . . Let us consider some of the difficulties involved in creating experimental programs incorporating these techniques and strategies.

The most vexing problem here is the interaction of technique and content in a program: experimental materials which are to be useful for evaluation experiments must not only embody the techniques and strategies to be studied, but must embody them in materials of adequate intellectual and esthetic quality. A second problem is connected with program size. On the one hand, it is very desirable that an experimental instructional program cover a large enough unit of commonly–understood content so that student performance can be evaluated in a straight–forward way with a minimum of redundant "control" experimentation. On the other hand, the quantity of mere writing in an experimental program can be very large in proportion to the instruction achieved. Writing a one–year program in any subject is not merely equivalent to writing a textbook covering a year's work. A program must be thought through in much finer detail than a book, especially if the programming follows a non–conventional pedagogy.

Therefore a project to prepare a large experimental program requires . . . at the present "invention stage," . . . subject–matter experts working on a full–time "saturation" basis, unencumbered by other responsibilities and aided by substantial technical and clerical help. It is important to simplify and automate the programming job to whatever extent possible. . . . A set of user–specialized program routines . . . prepared in the form of a "programming language," can greatly expedite translation of pedagogical ideas into executable programs. It is also important to have efficient means of reusing each programming technique on new material with a minimal amount of reprogramming. Generally speaking, this means that the programming language and procedures should accommodate "high–level" as well as "low–level" statements.

Since for most practical purposes the only satisfactory measure of the pedagogical value of a program is to see how well students learn from it, it seems important that testing be done using real students in a fairly realistic educational situation. However, for each subject area and educational milieu there are limitations on what kind of experimentation is permissible and, for given materials, what populations of students are available. . . . Attention must also be given to a number of potential difficulties of scheduling and logistics. . . .

Conclusion

The task of developing CAI is clearly a complex one. In my judgment it must be predominantly an empirical task. I think that, despite the existence of a considerable body of knowledge with regard to human learning and considerable expertise with regard to instruction, the primary resource required will be the intuition of creative teachers, curriculum specialists, and technical workers. . . .

I hope that this group will share my conviction of the great importance of pedagogy as a topic, and experimental programming as a vehicle, for early exploration. I also hope that, in its deliberations, the Conference will discover at least a few tasks or projects of immediate feasibility which might have special claims for Commission sponsorship, because I believe that physicists as a group are particularly well qualified by background and temperament to contribute to developments of the sort needed.

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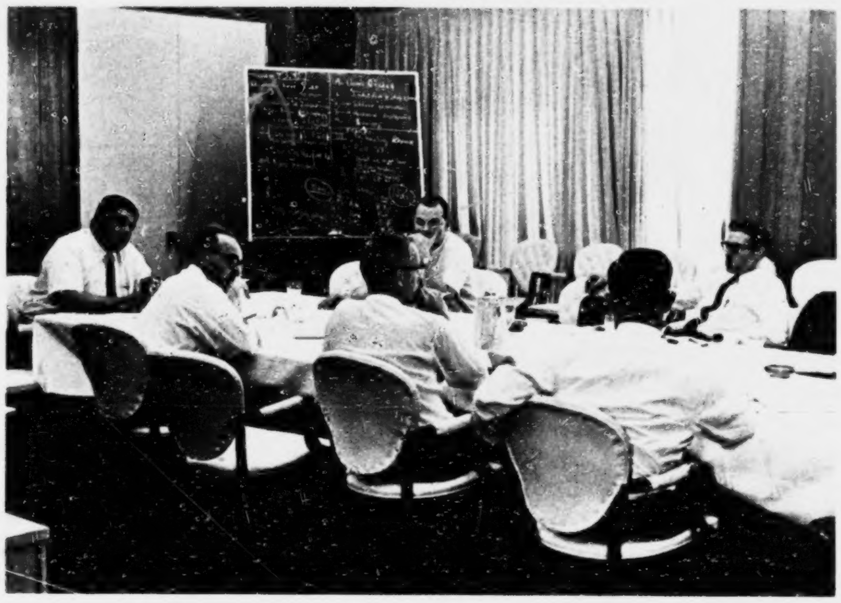

working group reports

- Curricular-Administrative Problems

- Pedagogical Techniques

- Systems and Equipment

Curricular-Administrative Problems[1]

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Our group report considers broadly the operational development of the computer as an instructional aid from the viewpoints of three parts of the educational system: the teacher, the student, and the administrator. From each viewpoint, in spite of the absence of actual experience, we have suggested some guidelines for future CAL experimentation.

The Teacher

Initiative in the educational system belongs to the teacher. Within this system both the student body and the administration produce some constraints, but the teacher retains a considerable amount of flexibility. Through his choice of lectures, the assignments he makes, his laboratory design, and the audio and visual aids he uses, he controls the presentation of material. He sets the pace for the student and determines the format within which the student must respond. Furthermore, he evaluates student response to these presentations and can alter the pace or the format as he sees fit. The Curricular–Administrative Working Group considered how the computer might augment, and even alter, the course structure and the teacher's personal contributions within that structure.

The elements from which an instructor designs his course can be classified under three main headings: presentation, student response processing, and feedback. A list of the common course elements under these headings is given in Table 1 (p. 00). Emphasis on one or another of these elements varies from course to course, so that it is difficult to make general statements applicable to all course varieties in physics; nevertheless, it is within this basic structure that the computer must make its contribution. It is therefore necessary to evaluate its capabilities against the requirements of such a system.

The computer will be least important as an element in the presentational mode. The student terminal and the associated computer system is too expensive for the student to use like a book. The lecture, text, and the other elements under the heading of presentation can therefore be expected to continue to dominate this mode.

It is possible that in some instructional formats the computer will play an important part in *choosing* and *ordering* materials for presentation. In an instruction session with a student, centered, for example, on a broadly-based review problem, the computer could be programmed to refer to a video tape section of a previous lecture or to a short demonstration film, or to refer to textual material. Such a program would make possible a presentation directed to the needs of the individual student.

The use of the computer in its computational mode[2] could also be classified as presentational (see the Report on Pedagogical Techniques and Appendix F). With the expanded computational capacity of a computer the student can be served more realistic problems as examples of the application of physics.

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[1] Edward D. Lambe, Chairman; E. N. Adams, Kenneth Ford, W. Thomas Joyner, James Kearns, Joseph Rosenbaum, Edward Turner.

[2] We distinguish in this report two instructional uses of the computer: the *linguistic mode*, in which the computer bases its presentation on the student's response; and the *computational mode*, in which the computer is used as a computing or data processing device.

Table 1

ELEMENTS OF PHYSICS TEACHING

A. Presentational

The instructor controls the method and emphasis of presentation. It commonly consists of:

1. Reading: textbook, or supplementary assignments.
2. Live Lectures: possibly supplemented by lecture demonstrations or films.
3. Films, TV, or Audio: these can be entire lectures, or segments dealing with a specific topic.
4. Direct Experience: the student's accumulated experience with his environment is an important, though uneven, resource. It may be supplemented by some of the following:
    a. Laboratory experiments
    b. Lecture demonstrations
    c. Corridor demonstrations
    d. Take–home experiments, toys, etc.
    e. Specially designed rooms to demonstrate a certain set of uncommon but important experiences (various aspects of motion, change in scale, etc.).

B. Student Response Processing

The success or failure of the individual students is based on the formal and informal responses required of the students.

1. Examination: formal response, calling for the student to demonstrate, at specific times, his understanding of the material presented.
2. Homework Problems: graded carefully, these provide achievement information at regular intervals.
3. Recitation classes: the student responds verbally to the presented material and demonstrates the state of his comprehension.
4. Laboratory: experiments based on the material presented in lecture or text.

C. Feedback

Student response which comes in quickly enough to influence the subsequent course-related activities of either the instructor or the student can provide information about the success of the course. All course elements listed under "Student Response Processing" can feed back some information, for example:

1. Examinations: information obtained is usually too late to affect the student and changes in the presentation by the instructor are usually not made until the next time the course is given.
2. Homework Assignments: most useful to the student, the unanalyzed results are difficult for the instructor to use as feedback.
3. Recitation: if this were handled by the course director, the feedback would be of great worth. However, the usual indirect mechanism is not very effective.
4. Other mechanisms such as questionnaires or informal group discussions, etc., are sometimes used to advantage.

At the present stage of development, computer technology will probably make its greatest contribution in the second and third categories of Table 1. In particular, the computer offers the possibility of on-line student response processing. A student should, in a properly designed program, be able to come to a terminal, work through a multi-part review problem, and have his responses to each step evaluated at once. This offers obvious advantages to either homework or exam problems for which evaluation comes long after the student has attempted the solution and is necessarily more a judgment of the whole than of the separate parts.

As far as its mechanical capabilities are concerned, the computer can provide much more feedback than is now normally available. It can (if desired) record everything the student does while signed onto the machine. The problem will be to decide what data to accumulate and how to organize its presentation.

The feedback is useful in three general ways: as a guide to the instructor in presenting new material and reediting material already presented; as an indicator to the student of his weaknesses and strengths; and finally, for cumulative bookkeeping of student progress available to the teacher for administrative purposes. To this latter category of information could be added a scholastic history of the student: his college board scores, high school standing, high school physics preparation, if any, professional interests, etc.

The possibility of reducing the delays in feedback and increasing its amount and usefulness (through better organization of the raw data) is exciting. To realize this, however, the art of programming will have to be further refined; the student must be allowed, for instance, to record his need for further information or explanation at any point. New interface techniques, and perhaps new equipment will have to be developed to allow for storage of the growing student history and to facilitate its quick readout and efficient presentation.

In addition, there is the intriguing possibility that the maturation of this instructional element, with its ability to hold many reins at once, may enable the instructor to allow the entire format of the course to depart from the present lecture-dominated lock step. If the full capabilities of the computer are used for keeping close watch on the progress of individual students, a flexible pacing, determined to a greater extent than at present by the student himself, may be possible. The instructor would set the intermediate check points and the final goals of understanding upon which the grade judgment will be made. He may then be able to leave it to the student to utilize the resources made available to him—lectures in some cases, textual material, assisted problem solving, laboratory, films, student-accessed demonstrations, etc.—to master the material. Through the computer the instructor can follow the progress of at least several separate classes of students, give aid or stimulation as it is needed, and generally concentrate on what a human instructor does best—using knowledge of his subject and his pedagogical experience to teach the student at the student's level of understanding.

The Student

Little is known about the effects on the student and the learning process of computerized instruction in physics. By examining the problems and potentialities from the student's viewpoint, however, we can perhaps make some suggestions toward fruitful directions of development.

As a study aid, the computer will permit the student to be a more active participant in the instructional system. An imaginatively constructed computer sequence can allow him to test himself at as fine an interval as he desires and to continually evaluate his own understanding. It should also allow him, to a certain extent, to pace himself, to call up more advanced parts of the program as he has absorbed and understood previous portions, and to repeat portions of the program which he finds difficult.

A computer-conducted recitation section has the advantage of privacy: the student need not fear the direct reaction of his peers and professors to his mistakes. He will, of course, recognize that each mistake may be recorded and made available to his instructor; but the length of time he requires to answer any one question need not be open to immediate criticism; and a wrong answer, rather than triggering immediate disapproval, can be corrected by the student, allowing him to proceed.

The computer can in this way lead the student to discover his own strengths and weaknesses and to detect the stumbling blocks that might otherwise inhibit his progress and discourage his desire to learn. With skillful programming, the CAL materials can help the student overcome these difficulties.

Finally, because the instructor will constantly be evaluating student performance at the machine, examination may become in part a continual process and thus a potentially less painful experience for the student.

We know least about the student's emotional and psychological response to computer–presented instruction. Results of student reactions to the few programs already in existence are sparse and inconclusive. They indicate only that programmers may have to develop more sophisticated response recognition techniques to allow students more latitude in their answers to computer–directed questions, and that most students require a thorough introduction to the machine and its operation before being asked to communicate with it in a learning situation. We recognize that for years to come physics programs for the computer will be experimental. The student's education should not be disrupted for the purpose of using him as a guinea pig. We recommend that new materials in computer–assisted physics instruction either be developed around topics which do not now form an integral part of the physics curriculum or that they be applied to course elements not now adequately exploited. In this way, the student's progress toward an understanding of fundamental physical concepts will not be impeded if for some reason a computer program fails to provide the proper guidance.

We recommend also that the accumulated experience with students be recorded in as much detail as possible to provide guidelines to future program authors.

The Administrator

The teacher and the student will measure the efficacy of CAL against a constant standard: the improvement in learning efficiency. The administrator will use another yardstick. He must be concerned with economy and in this measure must include not only instructional hour per dollar but also the more difficult measurement which might be loosely termed excellence per dollar. Before the administrator accepts CAL, he must be convinced that its effectiveness justifies its cost. Such a measurement will be difficult to make.

The new kinds of costs that the introduction of CAL techniques will put on administrative books are rather easy to enumerate. On the other side, however, the ledger must be balanced not only by the gain in understanding which the teacher will demand, but also by gains in the more elusive qualities which affect the overall atmosphere of a place of learning.

1. The Cost of CAL

As Appendix B indicates, CAL equipment is expensive. If the cost of the computer itself is added to the cost of terminal and interface equipment, it is enormously expensive. In most instances, the cost of the central computing system will have to be justified and amortized by research and administrative needs and not by its student use. The realizable cost per student hour of a central computer utilized optimally has been estimated by Karl Zinn:[3]

> **A commercially available computer programmed to handle students at twelve electric typewriters interacting simultaneously with any of twenty different courses costs under $10 per student hour at the teaching station. A smaller and less expensive computer shared by four student stations can be operated at less than $5 per hour per student. . . . Within three to five years, time–shared systems will cost about $1 per student hour at the teaching station.**
>
> **These cost figures assume that much instructional material is already stored in the computer and that students are scheduled to occupy all terminals for eight hours of computer time five days a week . . . . Once the initial investment in the preparation of self–instructional materials has been made, teaching stations connected to a time–shared central system can be used as very economical teaching assistants.**

Certainly in its early stages and for some time afterward the cost of preparing CAL materials will be more important and more difficult to estimate than the cost of physical equipment. The cost in terms of time and money will be shared by the university administration and the author.

Programming instructional sequences, especially in the developing phases of the art, will require the efforts of physicist–instructors, computer experts and programmers, as well as substantial technical and clerical support. Commitments of money, personnel, and space will have to be made for rather long periods of time; estimates of the ratio of professional man–hours of production to hours of student consumption are in the neighborhood of four physicist–years per student semester. The cost of the development of CAL techniques will have to be heavily subsidized by government agencies, private foundations, publishers, and manufacturers. Efficiency and economy will call for concentration of efforts at centers offering excellent computer facilities and personnel resources.

Private authorship will raise problems of compensation different and more complex than those occasioned by textbook writing. The preparation of CAL material will require more time than the afterhours allotted to text writing. CAL authorship will require substantial released time, the use of student terminals, computer facilities, and students for testing. Part of the incentive for authorship can be supplied by royalty arrangements. This will be particularly necessary for programs developed at one institution and used at another. In these arrangements the home institution, providing as it must a large share of the physical and financial support, would reasonably share in the royalties.

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[3] Karl Zinn, "Computer Assistance for Instruction: An Introduction" (unpublished paper, 1965), pp. 2–3, available from Dr. Zinn at the Center for Research on Learning and Teaching of The University of Michigan.

2. *CAL and the Educational Atmosphere*

Even were he able to design a measurement of understanding per dollar, no administrator would dare make this the unique measurement of CAL's effectiveness. He must in some way gauge the changes that the introduction of this new system will bring to the overall nature of his institution. It is impossible to anticipate all of these changes at this early stage. We can only suggest a few examples.

The expectation that students will spend a significant number of hours at the terminal must be reflected in an overall reduction of hours spent elsewhere. The realization of some of the possibilities of more flexible pacing may suggest changes in the regular allottment of course hours.

The most important concern may well come from apparent (or actual) further depersonalization of the educational system. The administrator will have to make certain that the interposition of a terminal and a program between student and teacher, in drill and recitation for instance, is compensated for by richer associations elsewhere—in seminars, student research involvement, etc. If the full potentialities of the computer to examine each student individually and to record and analyze his development are used to advantage, and if the instructor deals with the student from this deeper insight, the educational experience can become a more personal one.

Recommendations

From an administrator's point of view, what recommendations should be made to guide the trial developments that are now beginning? The first physics materials programmed should be modular, accompanying only part of a course. This will facilitate comparison of results with those in other sections of the same course and make their trial at other institutions easier. The administrator should demand that the development of physics programming techniques be paralleled by the development of a capability for sophisticated record keeping and analysis so that this aspect of CAL can be evaluated. Finally the administrators of institutions beginning experimentation with CAL must provide the imaginative leadership to work with funding agencies toward resolution of the complicated financing and compensation problems which will arise.

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Pedagogical Techniques[1]

The report of the Working Group on Pedagogical Techniques is divided into two sections. The first, computational mode CAL, illustrates some of the ways in which the computer can expand the computational possibilities open to students. The second, instructional mode CAL, considers the computer as a direct aid to instruction.

Computational Mode

The computer is fast becoming an indispensable scientific tool; it is rapidly being acquired by colleges throughout the country not only for research but also for all forms of computational and data processing assistance. Understanding of the capabilities and limitations of this computational aid, the logic of its operation, and the mathematical techniques suitable to it, is, along with some experience in its use, a necessary part of the training of the prospective physicist. We suggest here a use of the computer in instruction which can provide this familiarity and at the same time extend the breadth and depth of physical problems open to solution by the undergraduate student.[2]

By solving complex physical problems with a computer, a student can gain experience not only with analytic relationships and analytic methods of treating a problem, but also with actual numbers and with numerical methods. In a properly conceived instructional program, quantitative and analytic techniques can complement and illuminate one another.[3]

The speed of computer solution enables the student to examine many more specific problems than he could reasonably be expected to solve by hand calculation. The computer can thus increase his experience with, and intuition for, various physical situations.

Furthermore, the use of numerical analysis permits the instructor to consider material which analytically would exceed the student's level of sophistication. For example, with the help of a computer, a teacher can discuss the Schrödinger equation for the harmonic oscillator even with beginning students.[4]

Finally, the fascination that computers hold for most students can and should be exploited for pedagogical purposes.

Identifying the parts of a physics course that lend themselves to computer assistance and developing the necessary programs for physics may well present serious barriers to further use of the computer as a computational tool for students. We recommend that there be a method of rapidly distributing and exchanging information on computer programs already developed of the sort described in Appendix E. This could be done in the form of source program listings in any of the semistandard compiler languages—FORTRAN, ALGOL, BASIC, JOSS, etc.—supplemented by short abstracts describing how the programs could be used in physics teaching. Many such programs already in existence could easily be adapted for use at institutions other than the originating school. If the efforts of individual physics teachers to develop new materials are made available through the *American Journal of Physics*, the Commission on College Physics, or through some other means, physics instructors will hopefully be able to draw on a repository of ideas and materials for computer–assisted physics instruction in much the same way that they now draw on collections of lecture demonstrations and laboratory experiments.

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[1] Donald Brown, Chairman; Alfred Bork, Leonard Jossem, Arthur Luehrman, Thomas Padden, Donald Shirer, Malcolm Strandberg (Computational Mode subcommittee); Arnold Arons, Kenneth Davis, Wallace Feurzeig, John Fowler, Frank Harris, Robert Hulsizer, Thomas Palfrey, Richard Walther (Instructional Mode subcommittee).

[2] See Appendix E for detailed descriptions of five examples of programs in which the computer has already been used in this mode.

[3] See Appendix E (the Lattice Vibration Spectrum).

[4] See Appendix E (the Harmonic Oscillator in Quantum Mechanics).

Appendix E may be considered as the first edition of such information for computational mode programs. The CCP accepts the responsibility of seeing that this list is kept up to date as more programs become available.

Instructional Mode

The use of computers as direct aids to instruction, rather than as computational devices, has had little application in the teaching of physics. Instructors and administrators will judge the importance of the computer as an instructional tool, but they will do so only after comparing the cost and advantages of CAL techniques with those of such existing materials as programmed texts, autotutors, conventional audio–visual aids, and of course text, lecture, and recitation. In this section of our report, we shall try to identify those instructional elements[5] whose functions could be better exploited with the help of the computer.

The computer seems to be poorly adapted to straight presentation of ideas; it operates most effectively as a response processor and is uniquely suited to collecting, analyzing, and presenting feedback information. We describe below the instructional forms in which the computer might supplement or supercede an inefficient mechanism, or open up a new possibility in learning assistance. These CAL forms are considered in descending order of priority as we see it at this stage of development.

Guided Problem Solving

There seems to be general agreement that the most keenly felt student need, and the need for which help is most difficult to come by, is for day–to–day assistance in problem solving. It is in this exercise that the student tests his understanding of the material presented in lecture and text, and gains some numerical familiarity with physics. It is here also that individual attention of a rather routine form could be most useful.

Using a computer, an experienced teacher should be able to prepare a program which anticipates sources of student confusion and, by pointing back to previous problems, to lecture or text, or by providing the next small step, removes the difficulty and allows the student to proceed on his own. Some grading mechanism could be developed, based on records of each student session, if desired. The optics unit produced at the Seattle Conference[6] and described in Appendix C has as one of its elements the first approximation of a computer program designed to give help on assigned problems.

A second type of computer–guided program for problem solving might be more tutorial in nature. For example, a CAL unit might be immediately valuable between the time the student attends a lecture and the time he is examined on the material. Creative use of CAL to provide an opportunity for review and self–testing, perhaps in conjunction with other programmed materials, could allow the conscientious but uncertain student to better prepare for the exam hurdle.

Diagnosis and Tutorial–Remedial Help

We see considerable use for CAL materials of the tutorial–remedial type. These routines can be of a straight remedial nature made available to the student for diagnostic purposes, for self–placement, or for help in correcting deficiencies. Such help would be most useful early in a course when differences in preparation are the most disadvantaging. The programmed kinematics unit described in Appendix C is a primitive example of remedial use.

CAL diagnostic techniques could be devised to help the student find his areas of weakness and to then branch him to a remedial loop. The particular advantage of the CAL mode here is in the area of what Arnold Arons has called "the tricky, difficult and blocking ideas" which are not necessarily complex or advanced, for example the "sensation of weightlessness" for which Arons has constructed a tutorial sequence.[7] The value of CAL modes for presentation of such material is that the student can take as much time as he needs for understanding. Furthermore, an idea can be presented in a wide variety of ways to help clarify those points which later in the course often cause great confusion.

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[5] See Table 1 (p. 10) for a breakdown of the traditional elements of a physics course into its three modes: presentation, response, and feedback.

[6] Working Conference on New Instructional Materials held at the University of Washington during summer 1965.

[7] This tutorial program is described in Appendix C and a complete flow diagram showing its logical structure forms Appendix J.

Computer Laboratory

In general we feel that although the computer–aided laboratory has much to recommend it, the advantages can easily be exaggerated. The computer can be used to present the student with problems which he solves at the lab bench and presents at the terminal for verification. At this point he is branched to one of a variety of subsequent operations depending on the adequacy of his findings. Such a sequence is being tested in the optics unit mentioned earlier.

The computer could also be interposed between the student and a particularly dangerous experiment or one using equipment too expensive to jeopardize. The student could then be given relative freedom to run the experiment and collect data, but with built–in protection for himself and the apparatus.

Obviously the use of computers in any of these ways could reduce the numbers of laboratory assistants required and provide increased flexibility in lab scheduling. Labs could be open for longer hours; Stony Brook, for example, is looking toward at least sixteen–hour scheduling periods.

It has been suggested that a CAL program could be written to simulate laboratory experiments. We would, however, counsel strongly against too much reliance on the computer for such a task. It is largely in the laboratory that the student is introduced to the real world of physics. He should have the privilege of interacting with real objects of that world and learning the look of real data. It is our feeling that the computer lab, other than for computational purposes, should be used only in ways which assure this contact with the phenomena. Simulation is useful only when the model itself has some significance (in a Monte Carlo computation, for instance) or perhaps to reproduce an experiment not accessible to a particular laboratory (simulated nuclear scattering).

Finally, the committee felt that physics laboratories are often too rigidly organized, forcing all students into the same program. With imaginative programming the computer could be used to assess each student's progress and allow him to be placed at the appropriate level and to proceed at a pace more nearly his own.

Required Hardware and Software

Our considerations of the pedagogical purposes to which a computer might profitably be turned have led us to compile a brief list of desiderata in terms of hardware and software which would facilitate the accomplishment of these purposes.

Hardware that will allow input to the compiler as typed words or typed algebra is essential. In addition, graphic input with light pen or tablet sketch pad would be immediately useful.

Especially in the early stages of program development, on–line communication between author and student and on–line editing will be necessary.

One would occasionally want to use page–size display capability for quick presentation of text. For this, teletype seems too slow. "Thumb–through" paging in both directions for successive development of diagrams and the capability of monitoring the page usage for author records are also desirable.

The software must complement the hardware, and must provide for information storage and quick and easy retrial editing. A compiler eventually capable of keyboard recognition, algebraic checking, and natural language processing will be needed for the sophistication anticipated.

Questions and Recommendations

The working group raised one question basic to the use of the computer in teaching; namely, have CAL techniques a significant advantage over those possible with the much less expensive printed programs? A convincing answer to this can only be made after real comparative trial. As an exercise to provide some insight, however, we simulated a tutorial dialogue,[8] in the course of which two advantages of CAL techniques over programmed text became apparent. First, computer presentation allows the student to *construct* an answer and this constructed answer need not be influenced by a list of possible answers; nor is the student exposed to the correct answer. Second, trial assays on the student's part are encouraged and do not affect the eventual judgment of the instructor. These gains—especially the first—seem to be important. To them should be added the fact that the computer's branching capacity vastly exceeds that of the printed program. The hoped–for ability of the computer to allow the responses to take the form of diagrams, numerical answers with a range of correctness, or algebraic statements with a computer-controlled decision as to their correctness, will further increase its advantage.

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[8] In this simulated tutorial dialogue Arnold Arons played the role of a computer terminal and Robert I. Hulsizer acted as the hypothetical student. The student approached the terminal for help on the following problem: "A rocket of initial mass M_0 exhausts its fuel at a fixed velocity, v_e, relative to the rocket, and at a constant rate of $\dot{m}$. It is shot vertically upward. Neglecting earth rotation, find what determines the final rocket velocity, v_f, and what values of v_f are possible." The remainder of the experiment took the form of a question–and–answer dialogue of the type which might be programmed and which resembled the kind of questioning an experienced teacher might use when responding to a student's request for help on a problem.

We suggest that the following principles should typify the spirit of CAL development.

1. *CAL materials should not be introduced casually into an existing course format.* They must be integrated with the other instructional elements, and this can be expected to require considerable reformulation of the mechanical structure of teaching.

The time spent on student-teacher interaction, laboratory work, discussion-recitation sections, outside reading, problem solving, etc., will have to be reexamined. At present we cannot make reliable estimates of how the students' and instructors' time would be affected. Information will become available as trial courses are formulated and tested.

2. *Computer-presented materials should not be expected to carry an entire college physics course.* CAL should be viewed as an exciting new technology that deserves further exploration and exploitation, but only as one of several teaching elements. It should be integrated into present modes where it can clearly offer better and/or more economical ways of teaching. The increasing problems of enrollment and shortage of trained personnel make such an effort almost a moral demand.

3. *The aim of CAL techniques should be toward the preparation of the student for independent study and toward the increase of his capacity for self-direction, creativity, and understanding.* There is a fear that enthusiasm for this new technique will cause authors to program too finely and to attempt to lean too heavily on CAL, and thus to interfere dangerously with the ultimate goal of physics instruction—namely, the development within the individual of the capacity for self-instruction.

4. *Not all students should be required to take all parts of a CAL program.* One consequence of the availability of CAL would be to increase the modes of learning available to a student. Indeed, one of the strengths of the automated instructional system is that it gives the instructor freedom to provide a greater variety of instructional opportunities and educational environments, both within the system and outside. But students differ in their ability to interact with differing teaching modes and to profit from them.

We urge that the physics profession and the CCP in particular support vigorous experimentation with this promising technique. Only by careful planning from the beginning can we assure that technology will enter teaching as it has entered other areas of human endeavor, not as a substitute for humans but as a means of amplifying the uniquely human contribution.

Systems and Equipment[1]

The Systems and Equipment Group report is designed to guide departments of physics which have not as yet devoted significant attention to the use of computers in undergraduate physics instruction, but who wish to do so in the near future. In particular, we are talking to those departments located in institutions having no strong current program in the general field of computer-assisted instruction.

We have attempted to characterize briefly[2] the equipment and systems currently available for use with students, and then to indicate the principal needs and possibilities for action in computer-assisted physics instruction this fall (1966). Finally we consider the equipment and systems needs of those who aim for operational status in the fall of 1967 or 1968. Beyond 1968 our crystal balls are not cloudy; they are opaque.

It is clear to us that any system to be operational by the fall of 1966 must make use of presently existing hardware and software. For example, it appears that prospective authors without access to one of the experimental user languages have no choice but to use COURSEWRITER[3] for the preparation of instructional materials.

For computational mode CAL, however, new users can arrange access to one of a number of already operational dialing systems. Using one of the less sophisticated remote console devices (e.g., Teletype or IBM 1050), simple computational course material could be prepared for experimental use with small classes in the fall of 1966. Examples of such dialable computing systems are JOSS[4] at RAND and System Development Corporation (SDC); modified versions of JOSS at the University of California at Irvine and at Bolt Beranek and Newman; BASIC[4] at Dartmouth; and commercially-available service in QUIKTRAN[4] from IBM and BASIC from General Electric. A more sophisticated capability, such as Glen Culler's on-line system at the University of California at Santa Barbara (described in Appendix F), involves a more elaborate remote console, but can still operate over telephone lines. In fact, consoles connected to the UCSB system via phone line are currently in operation at the University of California at Los Angeles and at Harvard University.

For those who seek to develop physics programs for use in fall of 1967 or 1968, the possibilities are much more extensive. As we discuss these possibilities, we make the assumption that a central computer is available, either locally or through a communication line, and recommend that it have the following features: first, hardware to permit time-sharing operations; second, an adequate complement of time-sharing software for housekeeping operations, monitor operation, computing languages, interpretive schemes, and so on; third, modular design so that the machine may be readily expanded; and fourth, a direct-access mass memory including disk, drum, and data cell storage, or some combination of these elements. We estimate that there will be approximately twenty such machines in operation by fall 1967 and approximately fifty by fall 1968. These will be distributed across the country in such a way that by 1968 every institution will be within 500 miles of a machine.

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[1] Burton Fried, Chairman; Bruce Arden, Charles Branscomb, Harry Cantrell, Richard Gooch, Everett Hafner, John Kalbach, Andrew Kleinschnitz, William Lonergan, George Michael, Peter Roll, Noah Sherman.

[2] Detailed information appears in Appendix A ("Linguistic Mode Computer Systems"), Appendix B ("Remote Console Equipment"), and Appendix C ("Linguistic Mode Physics Programs").

[3] See Appendix A for a brief description of the COURSEWRITER language.

[4] See Appendix G for brief descriptions of these computational programming systems.

Characteristics of Student Console Systems

Given this general geographic availability of large time-sharing computer systems, what kinds of remote and local consoles can be used by an institution which seeks to enjoy some of the facilities of a system located as far away as several hundred miles? Without attempting to include all possibilities, we can categorize such consoles, in increasing order of cost and capability, as follows:

1. *Remote consoles which can be serviced over a telephone line alone, and for which, at the user's end, no logical circuitry beyond a standard telephone data set is required to connect the console to a telephone line.* Examples include a conventional input–output typewriter or a typewriter together with a paper tape reader and punch, which allows users at the remote location to prepare small programs on paper tape and to load them into the computer. Consoles of this kind are commercially available (see Appendix B).

2. *Remote consoles which operate over telephone lines but require some equipment at the user's end to interface the console to a standard data set.* We will outline here three examples of such consoles. The first is a typewriter combined with a visual display device such as a slide projector, and an audio device such as a tape recorder. (Experimental equipment of this kind has been developed by IBM and by the PLATO project at the University of Illinois [see Appendix A].) The second combines a keyboard (i.e., no output writer) with an oscilloscope capable of generating alphanumeric characters only. The third consists of a keyboard with an oscilloscope capable of producing not only alphanumeric characters, but also such graphic displays as curves and other two–dimensional plots. (Consoles of this type using a storage oscilloscope have been produced by Bolt Beranek and Newman and are currently in use at UCSB, at the Harvard Computer Laboratory, and at the UCLA physics department.)

As additional options for this more sophisticated kind of console one could include an output writer and a plotter to give permanent "hard" copy versions of the graphic displays, and a graphic input device such as Bolt Beranek and Newman's Graphacon and the RAND Tablet. Note that these options do *not* include such dynamic graphic displays as the MIT SKETCHPAD and similar developments which typically involve the CRT presentation of rapid motion–picture–type displays.

Economics may require that these more elaborate devices be driven in parallel, in the sense that one piece of remote interface equipment services more than one independently–active console. Moreover, some of the optional devices, such as the output writer and plotter, can serve several of the standard consoles simultaneously.

3. *Local consoles located with a few thousand feet of the computer.* All options given under 1. and 2. above are of course available, but the economic factors may in some cases be quite different. In addition, the very large data transfer rate over a short transmission line makes possible dynamic graphic displays which are not feasible over a telephone line. It is clear that many other things could be done with local consoles which will not be possible with remote consoles within the next two years. For example, in a local console visual displays are possible using inexpensive commercial TV receivers. These would permit the presentation of pictures with the fine detail of commercial television, as well as the display of text at a rate far beyond the reader's power of absorption. It is nevertheless our suggestion that restraint be exercised in developing course materials making *essential* use of facilities which cannot feasibly be enjoyed by remote users. This does not rule out experimental work involving complex displays, nor does it restrict course development in which TV text displays are used locally, with some sort of permanent copy display (e.g., slides or video tape) at remote terminals.

One or two remarks about the economics of consoles are in order. What number of consoles would be sufficient to handle a class of freshman students? At The University of Michigan, for example, it appears that fifty to one hundred consoles would be required just for physics. This seems to us to be economically unreasonable for the next few years for most institutions.

Aside from economic considerations, the lack of tested physics material at the present time makes it *undesirable* to consider widespread, large-scale use of computer-assisted instruction. During the next two years or so, however, it should be feasible for a department having local or remote access to a central computer to use ten or fifteen consoles. This number should be sufficient for the development of instructional material by the staff, for limited use with large classes of some materials already produced and available, and for more general instructional use at the intermediate or advanced level.

Recommendations

For those who intend to begin using computers for physics instruction in the fall of 1967 and 1968, we recommend the following actions. First, physics departments (or any other potential users) should arrange in the near future for cooperative use of a distant central computer, or should initiate appropriate action to secure the necessary computing facilities locally. If the latter choice is made, users should remember that the lead time for a new system (including the raising of funds, selection and ordering of equipment, and so on) is likely to be at least two years.

Secondly, development or acquisition of software appropriate for physics instruction (author languages, instructional programs, on-line computing languages, and so on) should be initiated.

And finally departments should choose the type or types of consoles which will fit their needs. Prompt and specific requests to manufacturers for such consoles are indispensable if equipment that is technologically feasible and functionally desirable is to become available within the time scale considered.

The professional staff of the central computing facilities, whether local or remote, have the obligation of providing an adequate interface, both hardware *and* software, between the computer and the remote consoles. In the light of present technology this interface problem does not appear to be very difficult, but it must receive adequate attention. The consoles described above are, as already noted, technologically feasible on a relatively short time scale. Nevertheless only a few of them are presently commercially available. A concerted effort by the computer industry will be required if such equipment is to be available at a reasonable cost two years from now.

The activities described above will typically involve a cooperative effort among several institutions on a statewide or perhaps regional basis. We expect that neither the user department nor the computer facility will be able to bear a large fraction of the cost at either end of the communication line, and that support from appropriate federal, state, or private organizations will be necessary. It is important that this situation be brought to the attention of the National Science Foundation, the Office of Education, and appropriate private foundations so that they realize the technological possibilities and the necessity for providing funds on a sufficiently broad basis to allow this kind of cooperative action.

We feel that working sessions devoted to the development of and experimentation with the new kinds of software and hardware discussed above can make a valuable contribution to the development of CAL in physics. It is therefore recommended that one or more small working groups be organized for the summer of 1966,[5] as well as for the following summer.

One action which can be taken by departments which have not previously attempted to work in the area of computer-assisted instruction for undergraduate physics is to have staff members visit one of the centers mentioned in Appendix A, where facilities and experimental programs are in use. Visits of a few weeks or more would enable interested staff members to experiment with the instructional material available, to make judgments concerning its adequacy for their needs, and to suggest the kinds of improvements they would like to see available at the time they acquire their individual consoles.

The Report of this Conference contains a reasonably complete listing of the physics instructional materials which have been prepared to date. We recommend that the Commission on College Physics or some other group keep this listing up to date, publicize future additions to it, and arrange some means for communication and exchange of materials between the developers of instructional materials and prospective users.

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[5] This recommendation has been carried out; groups will be working at the MIT Science Teaching Center and at the Stony Brook campus of the State University of New York during the summer of 1966.

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appendices

- Linguistic Mode Computer Systems
- Remote Console Equipment
- Linguistic Mode Physics Programs
- Four University-Based Systems
- Computational Mode Physics Programs
- University of California, Santa Barbara, Computer System
- Computational Mode Computer Languages
- Glossary
- List of Participants
- Flow Diagram: "Weightlessness" by Arnold Arons

appendix a

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Linguistic Mode Computer Systems

Three large–scale systems exist at present (early 1966) which are suitable for the preparation of computer–assisted instructional material in physics. Of these, the only one currently available over telephone lines is the IBM COURSEWRITER system. Bolt Beranek and Newman's Socratic system using the MENTOR language has been tried experimentally in medical diagnosis, but has not been used for physics. It may become available in the near future on BBN's new time–sharing system. The University of Illinois' PLATO system will soon be available to a few cooperating institutions over telephone lines. In addition to these three rather sophisticated systems, a simple question–and–answer language, COMPUTEST, has been developed for the IBM 1620 computer. Finally, an author language is under development at System Development Corporation (SDC).[2]

The IBM COURSEWRITER System

In brief, COURSEWRITER is an interpreter language of about twelve executable instructions or operation codes and ten manipulative commands by which an author at an IBM 1050 terminal enters and edits text material and branching logic into the disk storage of an IBM 1401, 1440, or 1460 system. The edit commands include insert, delete, and type, and can reference text by line only. When the student is operating at the 1050 terminal, the computer interprets the stored instructions to present reading assignments, questions, and replies to student answers. The student types the responses he has constructed on the keyboard, and these responses are entered into the computer for comparison with alternatives previously stored by the author: the match between student answer and computer alternative determines the next computer reply. In achieving a match, the author can specify a variety of conditions for recognition of responses other than an exact match, including the presence of a portion of a given list of items, and the ignoring of trivial characters, such as space and tabulation, in the student response. The operating system consists of a monitor, a compiler, and programs to handle student registration and record keeping. This latter feature permits the author–experimenter to accumulate and summarize data on student performance and on characteristics of particular items or sequences in the instructional program.

Detailed specifications for the 1050 teaching terminal can be found in Appendix B. Briefly, it consists of a Selectric transmitting typewriter plus (optional) facilities for random access visual and audio files under computer control. Transparencies showing text, diagrams, or photographs of lab equipment can be displayed with an 80–slot Kodak Carousel Slide Projector, and recorded messages can be played from a tape recorder which can be separately addressed for any message of ten seconds or more anywhere on a thirty–minute length of tape.

The commercially–announced version of the the COURSEWRITER system is available on the IBM 1401, 1440, or 1460 series of computers. The Watson

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[1] The following brief descriptions have been abstracted, with a little editing, from a paper prepared by Karl L. Zinn for the Association of Educational Data Systems Conference on Computers in American Education (Stanford University, November 1–3), 1965, entitled "Computer Assistance for Instruction: A Review of Systems and Projects." In *Proceedings of the AEDS-Stanford Conference on Computers in American Education,* edited by Don D. Bushnell and Dwight Allen (to be published in 1966).

[2] See Appendix D for a summary of how UCLA intends to use this programming system.

Research Center uses an experimental version with a time-shared 7010 computer using a 1440–1448 buffer multiplier input-output control system. Recently (late March 1966) IBM has announced the existence of the series 1500 Instructional System, for which a more advanced COURSEWRITER II language is available. The 1500 System has two significant advantages over the 1400 series with type 1050 terminals. It possesses a CRT output upon which characters and a limited amount of graphical information can be displayed, thus overcoming some of the display limitations and the slow speed of typewriter output. Secondly, the 1500 System is less expensive than the 1440 series. An efficient computational language, MAT (Mathematical Algorithm Translation), will also be available on the 1500 System. As presently announced, however, the 1500 System will be available only to selected research laboratories for use in the development of instructional materials.

Some of the locations where COURSEWRITER systems are in use in early 1966 include Florida State University (Donald L. Hartford), Michigan State University (R. Davis), Pennsylvania State University (Harold E. Mitzell), The State University of New York at Stony Brook (E. D. Lambe), the University of California at Irvine (Fred M. Tonge), The University of Michigan (Karl L. Zinn, Center for Research on Learning and Teaching), and the University of Texas (C. Victor Bunderson). Several of these projects do not have their own computer at present, but are tied into the Watson Research Center by long-distance telephone lines. A German course and several physics programs (described in Appendices C and E) are among the materials developed for experimental use in the COURSEWRITER system.

The following references contain further descriptions of the IBM system:

T. Hartman, *Audiovisual Instruction* (January 1966) pp. 22–23. This is a popular description of COURSEWRITER, including examples from a computerized German course.

1401, 1440 or 1460 Operating System for Computer-Assisted Instruction (IBM, Endicott, N. Y., Systems Reference Library Form C24–3253–1 [1965]).

A. Maher, *Computer-Based Instruction(CBI): Introduction to the IBM Research Project* (IBM, Thomas J. Watson Research Center, Yorktown Heights, N. Y., RC–1114 [1964]).

The Bolt Beranek and Newman System

Researchers at Bolt Beranek and Newman are giving particular attention to a system in which an author-instructor can implement training and testing of complex analytic tasks, such as diagnosing medical ailments, arriving at decisions in business and management, developing military strategy, and investigating scientific problems. For this they are developing a teacher-author language called MENTOR for use in constructing conversational tutorial dialogues. The instructional program in this system is in the form of logical expressions which determine computer replies and subsequent material on the basis of whatever aspects of the student performance history the author cares to designate. Typically, a situation is established in which a problem may be solved by the gradual acquisition of information. The student makes inquiries or declarations composed from a list of acceptable terms, and the machine processes these replies according to complex conditional rules described by the author. In the current system, a PDP–1 computer is used with a teletypewriter and occasionally with cathode ray tube display devices.

Wallace Feurzeig and Daniel Bobro have described the ideal characteristics of a system for programmed instructional conversations between students and computers, and have attempted to include these as far as possible in their systems:

1. The computer responds in terms of the previous portions of the conversation and in terms of the question of the moment;
2. The user has complete freedom, including the possibility of making irrelevant or inappropriate remarks;
3. The computer will always have something appropriate to say;
4. The computer can judge whether to delay information requested by the student;
5. The answers of the computer can be based on complex computations, such as simulations–for example, the student might suggest a military strategy or tactic, and the computer could quickly lay out an array of consequences;
6. Verbal interactions are in natural language, such as everyday English;
7. Questions or declarative statements may be introduced on either side at any time;
8. Nonverbal exchange may include tables, graphs, pictures, and sounds.

Work on the MENTOR system is being carried out by John A. Swets, Wallace Feurzeig, and Daniel Bobro at Bolt Beranek and Newman Inc., 50 Moulton Street, Cambridge, Massachusetts. A more detailed description of their approach, together with an example of a medical diagnosis program, has been published recently by Swets and Feurzeig (Science, **150,** 572 [1965]).

The University of Illinois PLATO Project

The PLATO (Programmed Logic for Automatic Teaching Operations) project at the Coordinated Science Laboratory of the University of Illinois (Donald L. Bitzer, Director) has developed a compiler language for writing teaching logics or patterns for their CDC 1604 system. It incorporates an extended FORTRAN with their own language (called CATO) for specifying the logical structure of an instructional sequence, and can accept CDC 1604 assembly language statements at any point. Thereby, the programmer has great flexibility and scope for preparation of basic patterns (such as tutorial, inquiry, and simulation) into which any author can later insert his particular teaching material. For example, using a tutorial logic an author need write only the text, right answers, and diagnostics to obtain a computer–controlled sequence of instruction; the computer has been programmed in advance to fit arbitrary text and answers into a particular type of dialogue. In another pre–programmed strategy, the author may insert any text which he wishes to evaluate; the computer has been programmed to ask questions and collect data during presentation to students according to a particular pattern. A third type of strategy being explored is simulation of laboratory or real world situations such as international relations. To accomplish these functions, special routines have been written for judging student answers by various complex criteria, plotting graphs on student request, plotting data from an on–line physics experiment, constructing and checking statements in a mathematical proof, monitoring physiological data entered over supplementary input channels, and controlling supplementary audio or visual displays.

The current operating system for PLATO includes twenty teaching stations with video capability. The author may project slides on a television screen via an "electronic book" and superimpose writing on diagrams by means of an "electronic blackboard function.[3] Student response is by teletypewriter keyboard, with the characters or special symbols appearing on the television screen at a location predetermined by the author or programmer. This television capability requires expensive wide–band (video) transmission lines between the central computer and remote terminals, thereby effectively limiting full use of PLATO to the University of Illinois campus in Urbana. Arrangements have been made recently, however, to make a more limited version of PLATO available over telephone lines at a few other institutions.

A wide variety of materials has been programmed in the PLATO system, ranging from pre–school through graduate level. Programs have been developed in a large number of areas for elementary and secondary school use. At the college level, programs have been developed in psychology and in several engineering subjects, and the system has been used on a semi–production basis for engineering instruction.

Further recent published information on the PLATO project is available from the following references:

R. Benjamin, "The Uses of PLATO," *Audiovisual Instruction* (January 1966) pp. 16–23. (A popularized account.)

D. L. Bitzer and J. A. Easley, Jr., "PLATO: A Computer–Controlled Teaching System." In *Computer Augmentation of Human Reasoning*, edited by

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[3] See Appendix D for elaboration of these functions.

Margo A. Sass and William D. Wilkinson, (Washington, D. C.: Spartan Books, 1965), pp. 89–104.

D. L. Bitzer, E. R. Lyman, and J. A. Easley, Jr., "The Uses of PLATO: A Computer-Controlled Teaching System." Report R–268, University of Illinois Coordinated Science Laboratory (Urbana, 1965).

J. A. Easley, Jr., H. Gelder, and W. Golden, "A PLATO Program For Instruction and Data Collection in Mathematical Problem Solving." Report R–235, University of Illinois Coordinated Science Laboratory (Urbana, 1964).

COMPUTEST

A simple, unsophisticated instructional author language has been developed by John A. Starkweather of the University of California at San Francisco. The COMPUTEST language permits the construction of simple question-and-answer dialogues, including a skip-ahead form of branching. It is characterized by the ease with which a person untrained in computer programming may write sequences of material. The common, inexpensive IBM 1620 computer with typewriter and card input/output is used. Preparation and input of instructions to the computer are by punched cards; the typewriter serves as the student station. The system includes the capability of grading the student's responses to questions. A more detailed description of this language can be found in:

J. A. Starkweather, "COMPUTEST: A Computer Language For Individual Testing, Instruction, and Interviewing." *Psychological Reports* (in press).

appendix b

Remote Console Equipment

I. INTRODUCTION

This survey is intended to provide the following kinds of information to physics teachers and others who are interested in the use of computers for instructional purposes, both in the linguistic and the computational modes:

1. Simple descriptions of some of the remote terminal devices and communication links available for use with large, fast, time-shared computers, as well as an elementary understanding of some of the technical problems involved in using them;
2. Approximate cost information for these devices and links, to provide some feeling for the overall amount of money involved in using remote computer console systems; and
3. Illustrations of possible uses of some realistic remote console equipment, in order to stimulate further interest, thought, and activity on the part of physicists.

Along with these three objectives, the following limitations of the information must be emphasized:

1. The survey certainly is not complete. Although we have tried to collect as much information as possible, some manufacturers have undoubtedly been overlooked, and the products of others surely are not completely represented. Furthermore, developments are so rapid that new products and improved models will have appeared between the time this was written (May 1966) and the time it is read.
2. Price information is only approximate. It does not reflect educational discounts where available, and could change in either direction according to market pressures and as improvements or modifications are incorporated into equipment.
3. A remote console system cannot be designed from the information given in this report. The various components described are not necessarily compatible with one another or with any particular central computer. Programs may not be available to utilize some of the devices with a given computer or with any computer, and they may have to be developed at the expense of the user. In short, *any system which is to be optimally effective and economical must be designed in collaboration with computer specialists, communications engineers, and manufacturers' sales representatives.*

Despite these limitations, it is hoped that the survey will provide a reasonably good general idea of the kind of remote console equipment available at the end of 1965, what it will do, and about how much the various components cost.

As illustrated in Figure 1(a), a remote console system, for either instructional or research use, may consist of one or more input-output (I/O) terminals connected to a control unit. The terminals themselves consist of devices to permit the student to communicate with the computer, plus other devices to permit the computer (or the teacher through the computer) to communicate with the student. In the former class, for

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[1] This appendix has been designed around a document prepared by Dr. Franklin H. Westervelt, of The University of Michigan Computing Center, for the use of his colleagues. To Westervelt's rather complete survey of devices manufactured and supplied by IBM, Digital Equipment Corporation (DEC), and the Bell Telephone System has been added some information on products of other manufacturers.

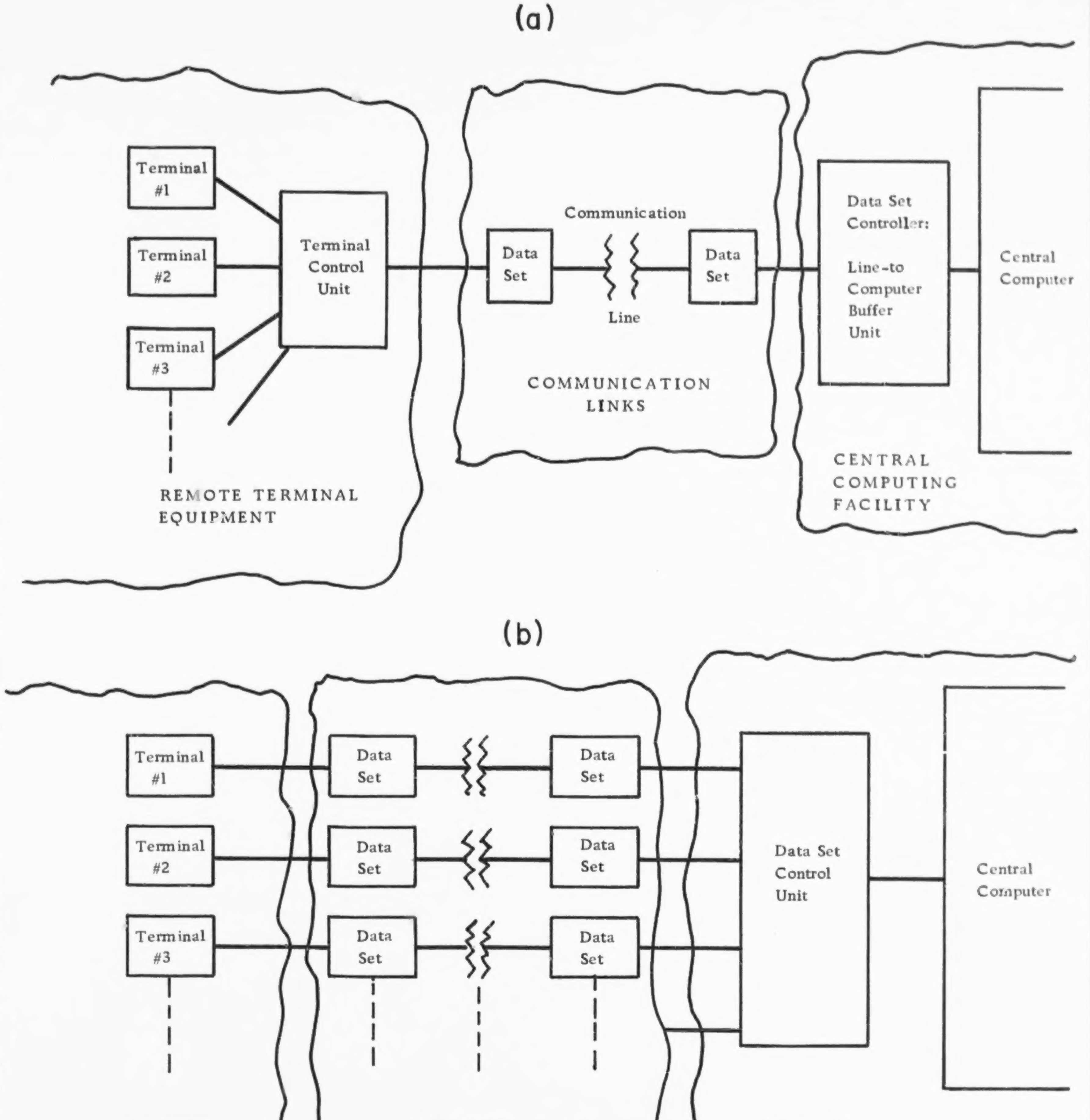
(a)
Terminal #1
Terminal #2
Terminal #3
Terminal Control Unit
REMOTE TERMINAL EQUIPMENT
Communication
Data Set
Data Set
Line
COMMUNICATION LINKS
Data Set Controller:
Line-to Computer Buffer Unit
Central Computer
CENTRAL COMPUTING FACILITY
(b)
Terminal #1
Terminal #2
Terminal #3
REMOTE TERMINALS
Data Set
Data Set
Data Set
Data Set
Data Set
Data Set
COMMUNICATION LINK
Data Set Control Unit
Central Computer
CENTRAL COMPUTING FACILITY

Figure 1

Block diagrams of typical remote station computer systems.
(a) Several remote terminals connected to the computer by a single communication line.
(b) Remote terminals connected to the computer by individual communication lines.

instance, are keyboards and light pens (for the input of graphic information), while output devices include typewriter printers, cathode ray tube (CRT) displays for alphanumeric and graphic information, film strip projectors, audio tape playback, and the like. More complicated terminals require a control unit to process the incoming and outgoing signals. For example, such a unit may provide temporary (buffer) storage for CRT displays, control circuitry and logic to operate film projectors, typewriters, etc., and time-sharing circuitry to permit the operation of several terminals from only one communication line. If such time-sharing is required, as shown in Figure 1(a), some kind of control unit is necessary. On the other hand, if simple terminals are connected to the computer by individual telephone lines, as in Figure 1(b), then the terminal can often be connected directly to the data set and communication line (this is true of a teletypewriter, for instance). At the computer end of the line, however, some kind of control unit is always necessary to sort out signals from and to the various terminals, to provide buffer storage for them if necessary, and to put them into a form which can be interpreted by the central processor. (In some cases this control unit may be built into the computer itself.)

In order to condition data signals properly for transmission over a telephone line or other communication channel, a data set is usually used at each end of the line. A data set is a telephone-like device with provision for dialing another party and for voice communication between the two ends of the line (the remote location and the central computer). It converts d.c. pulses from the terminal or the computer into audio frequency tones for transmission over telephone lines, and demodulates such tones into pulses which then can be interpreted by the computer or the remote terminal devices, respectively. In other words, the data set performs a generalized "impedance matching" function at each end of the communication link. The data sets on either end of the line must be compatible with one another, with the devices to which they are connected, and with the line itself.

This survey is organized to describe first, the remote terminal devices, including control units where necessary; second, communication links including data sets; and third, a visual display storage device which could be located at the central computer facility or at a remote, multi-console location. Within the first two categories, devices are listed roughly in order of increasing rate of data handling, which is almost equivalent to ordering by increasing cost. Because of the interdependence of terminal devices and communication links, it will be necessary to refer to the latter in discussing the former. Therefore, the reader must be prepared to skip back and forth until acquiring some familiarity with both areas.

For those not fluent in the language of the computer specialist, a brief glossary of some of the less familiar terminology is provided in Appendix H.

II. REMOTE TERMINAL DEVICES

Low Data Rate Terminal Devices

These are devices which can be connected to the central computer by voice grade or teletype communication links. As will be more fully explained in Section III, however, the designation "voice grade" refers both to ordinary dialable telephone lines, over which data can be transmitted reliably at rates of less than 2,000 bits/sec, and to special communication facilities which are designed to handle rates of up to 3,000 bits/sec or so. These special facilities include the leased lines lines available from AT&T (the Bell System) and Western Union, which are conditioned by them to meet the noise and bandwidth requirements of the user, and the Broadband Exchange Service of Western Union, a dialable network similar to the long distance telephone system but capable of higher rates of data transmission according to the subscriber's needs.

The first four terminals described below typically operate at rates of 1,200 bits/sec or less, and therefore can make use of ordinary local or long distance telephone services, and in some cases teletype lines. The remaining terminals in this group either require or operate more effectively at higher data transmission rates—usually at 2,400 bits/sec. Therefore they require special facilities: leased lines, broadband exchange service, or even one channel of a wide-band multiplexed TELPAK line (see Section III).

1. *The "Touch-Tone" Telephone*

The touch-tone (or pushbutton dial) telephone is probably the least expensive, but fairly general remote terminal device. It consists of a telephone equipped with pushbuttons rather than the usual rotary dial. When the buttons are pressed, a combination of musical tones is transmitted. Ordinarily this is used as a means of "dialing" the desired number of another telephone. Because the tone generators are contained in the instrument, they may be used after the usual telephone connection is completed. Thus, it is entirely feasible to use the pushbuttons to transmit data to the central computer after first dialing a special number.

It is felt that the twelve–button instrument should be specified to allow a fairly simple transmission of alphabetic code as well as numeric data, and to allow for error correction. The computer would return results in spoken letters, digits, and words using an audio response device at the central facility.

Typical monthly costs in a university Centrex system are:

Handset plus line	$8.75
Twelve key touch–tone feature	1.00
	$9.75/month

Other features to be considered are:

Extension phone	$3.50/month
Exclusion feature (to prevent errors from other phones on same extension during data transmission)	$ .25/month
Card dialer. (Allows transmission of precoded strings of tones [up to fourteen steps] from a punched plastic card. May contain stop codes so that more than one string may be held on a card. Cards are 5¢ each. Used for rapid dialing and for sending standard messages to log on, log off, etc.)	$3.00/month

The touch–tone telephone might be used to supply data and get answers from a program prepared on other, more versatile terminals; or it might be used in the laboratory as a means of setting up communication between an experiment and the central facility (see the brief discussion of process control units below).

2. *Model 33 and 35 Teletypewriters*

The Model 33 TTY (Teletypewriter) is a low–cost keyboard terminal able to send and receive messages at 100 ASCII words/min. (The American Standard Code for Information Interchange uses eight bits [eight-level paper tape] plus one start and two stop bits per character, a total of 11 bits/character. At 6 characters/word, the 100 wpm rate corresponds to 110 bits/sec). The Model 35 has the same capabilities but is designed for heavy–duty continuous use. Both the 33 and 35 are available in keyboard send and receive (KSR) and automatic send and receive (ASR), the latter incorporating a paper tape reader and punch. This equipment may be connected to the central computer by ordinary telephone lines, or by Telex or TWX lines (teletype exchange service of Western Union or AT&T, respectively).

Typical costs (**per month**) of teletypewriters leased from the Bell System are:

Model	**TWX Service**	**Data Phone Service**[2]
33 KSR	$45	$35
35 KSR	$85	$75
33 ASR	$60	$50
35 ASR	$125	$115

In addition, there is a non–recurring $25 installation charge. The cost of identical units leased from Western Union is comparable to the TWX rates. Thus, monthly terminal costs range from $45–$150. These terminals may be used to converse with the time–shared system in a full range of applications. Programs might be inserted, debugged, and run with interaction occurring after a delay of perhaps one to five seconds, depending on load and priority, etc.

3. *IBM Model 1050 Data Communication System*

A more versatile (and more expensive) terminal, the 1050 is likely to become fairly popular. Operating over voice grade or teletype lines at rated speeds up to 14.8 ASCII characters/sec (about 150 bits/sec), the 1050 may be configured in many ways to suit special needs and purposes.

One begins with a line and data set (at about $35/month) and a 1051 control unit ($75–$145/month, depending on features) to allow 1050s to converse with one another without using the central computing facility. One then may add various I/O devices as follows:

1052	Printer–keyboard	$65/month
1053	Printer only	$50/month
1054	Paper tape reader	$30–40/month
1055	Paper tape punch	$40–48/month
1056	Card reader	$60–97/month
1057	Card punch	$75/month
1058	Printing card punch	$95/month

There are system limits that control the number of devices which may be attached to each 1051. There are also some charges for special features that will probably be part of any 1050 installation.

A typical keyboard–printer terminal will cost about $168/month plus line and data set, or $203/month total. Adding paper tape reader and punch will result in a terminal charge of about $290/month total. This terminal is a very flexible conversational device, allowing access to a full range of time-shared system applications. It is the type of terminal now in use in the IBM QUIKTRAN system, in the MAC (Multiple Access Computer) project at MIT, and for the IBM COURSEWRITER system.

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[2] Additional charges for Data Phone service are $8.75/month for an ordinary telephone line and $25/month for the data set. The extra features make voice as well as data transmission possible.

Some 1050 terminals used with COURSEWRITER have been modified to include simple visual and audio displays. A Kodak Carousel slide projector mounted in the terminal is controlled by the central computer, which can be programmed to display the slides loaded in the projector magazine. Similarly, a tape recorder can be mounted in the terminal to play back previously recorded audio material under computer control. Since these accessories are relatively new and still somewhat developmental, no area prices are available.

4. *Honeywell Series 200 Data Station*

This all-purpose communication terminal was designed for business communication with a centrally-located Honeywell series 200 computer. It transmits and receives over a voice grade telephone line at 120 characters/sec, using a Data Phone 202C or 202D data set. The system is of modular design and may include keyboard, printer, paper tape reader and punch, card reader, and optical bar code reader. The data station can be used off-line for such activities as data preparation and editing. In many respects it is similar to the IBM 1050 series equipment, although it has not been adapted for use in an instructional system.

The monthly costs of components in an H-200 Data Station system are approximately as listed below on a ninety-day lease basis. Somewhat lower rates prevail for longer leasing terms.

288-1 Central Control Unit (the basic terminal, which connects to data set and telephone line)	$155/month
Keyboard	$30/month
Printer, 10 characters/sec	$65/month
Printer, 40 characters/sec	$180/month
Paper tape reader	$60/month
Paper tape punch	$88/month
Card reader	$70/month
Optical bar code reader	$260/month
288-1M Control unit (interface between telephone line data set and the H-200 computer to handle one data station)	$40/month

More complex control units are available to handle multiple data stations. When stations are close enough to the computer, data sets may not be required.

5. *The Bolt Beranek and Newman (BBN) Teleputer*

Suitable primarily for CAL in the computational mode (as well as for use as a research tool), this terminal has been described in some detail by one of its developers, Glen J. Culler, in an invited paper presented at the Irvine Conference (see Appendix F). Briefly, the console consists of a double keyboard, one for function operators (sine, expon, add, mpy, etc.) and one for operands, plus a five-inch storage oscilloscope unit on which alphanumeric as well as graphic information can be displayed. Details and examples of how this terminal functions and how it has been used for instructional purposes are given in Appendix F.

Although the BBN Teleputer is intended for operation with full duplex 2,400 bits/sec communication links, it has also been used with ordinary dialable (2,000 bits/sec) telephone circuits.

Purchase prices of the various components of the system are approximately as follows:

BBN Teleputer	$5,000
Teleputer Control Unit	
Standard model (handles up to 16 terminals)	$25,000
Improved model (handles up to 32 terminals with improved vector generation characteristics)	$40,000
Western Union or Bell System 201B Data Set	$70/month
Data Set Controller Unit (may be necessary with some central computers)	$10-20,000
Printer Output (Teletypewriter)	$2,500
X-Y Analog Output Plotter	$2,000
(ρ, θ) analog-to-digital input arm, for input of graphical information by tracing graph with stylus	$4-$5,000

The last three items in this list are under development and may be available by the time this report is available. Also under development are translations of Teleputer programs, developed for the Ramo-Wooldridge RW400 computer, into the languages of some of the new time-sharing computers appearing on the market (e.g., GE, CDC, IBM). As terminals of this sort develop and come into more widespread use, the number of hard- and software accessories can be expected to increase, along with the "performance per dollar" ratio.

6. *IBM 2260 CRT Displays*

The 2260 is a 4″ × 9″ cathode ray tube display and buffer for alphanumeric text material. Characters are represented in a 5″ × 7″ dot matrix. The character set includes thirty–six alphanumeric, twenty–five special (including space and new lines), and three control characters. Transmission is at 2,500 characters/sec when the display is directly connected to the 2848 Display Control by up to 2,000 feet of multiwire cable.

Truly remote operation requires a communication link between the computer and a remote 2848, using an adapter unit and data sets. Since the 2260 is alphanumeric only, a voice grade link is possible over either dialable or leased lines, using 202 or 201 series data sets (up to 1,200 or 2,400 bits/sec, respectively).

The basic 2260 is $30/month, but it requires various special features in order to be useful for most text display problems. Vector generation (efficient construction of lines and curves on the CRT) is not available on this equipment.

The alphanumeric keyboard is $20/month.

The 2260 will display either 240 characters, 480 characters, or 960 characters/station depending on its adapter and 2848 control unit.

The adapter will drive two 2260s and leases as follows:

240 characters	$40/month
480 characters	$80/month
960 characters	$100/month

The 2848 display control drives several 2260s as follows:

240 characters–24 stations	$360/month
480 characters–16 stations	$390/month
960 characters–8 stations	$420/month

If more than two adapters are needed, an expansion unit at $45/month allows up to six additional adapters. If hard copy is required, the units may be adapted to the 1053 printer for an added $10/month. A cursor feature (see glossary, Appendix H) to facilitate editing adds $10/month, as does the capability of addressing the display by line of text.

To simplify all of this, suppose one considers a remote installation of six 480–character 2260s with alphanumeric keyboards, cursors, and line addressing. Such a terminal installation leases for about $1,055/month or about $176/month/display.

7. *The IBM 1500 Instructional Station*

Just prior to press time, IBM announced the restricted availability of a series 1500 Instructional System. Features of this system are described briefly under the discussion of the COURSEWRITER language in Appendix A. The 1500 Instructional Station equipment apparently is not designed for use independently of the entire system. Since the relatively small IBM 1130 computer is used as a central processing unit, the announced remote terminal equipment is intended for use within a few thousand cable feet of the computer.

A series 1500 Instructional Station (the remote terminal) can consist of some combination of the following devices.

a. The 1510 instructional display with keyboard. This is a keyboard input–CRT output device similar to the IBM 2260 display unit. A complete set of alphanumeric characters with superscripts and subscripts, a cursor symbol, light pen, and other features are available on the 1510.
b. The 1518 typewriter input–output can be used in place of, or in addition to, the 1510 CRT display.
c. The 1512 image projector is a cartridge film–strip projector controlled by the computer, with each frame of the film individually addressable.
d. An audio tape drive–play and the 1505 audio adapter permit the presentation of audio material to the student, and also the recording of a recitation if desired.

Up to thirty–two remote stations, assembled from the units described above, may be connected through a 1501 Station Control unit to the central processor. The Station Control unit contains its own 24,576–word core storage and control circuitry for disk storage units. Because the 1500 Instructional System is to be made available only to selected research groups for developmental CAL work, no approximate prices are available. A complete system is alleged, however, to be somewhat less expensive than the series 1400 COURSEWRITER system using IBM 1050 terminals.

8. *Raytheon DIDS–400 System*

This Digital Information Display System (DIDS) includes CRT, character generator, refresh memory, and power supply. Alphanumeric keyboard and hard copy print–out are optional. With local buffering (storage), up to 1,040 characters can be displayed in less than four seconds using a 2,400 bits/sec communication link. A movable cursor is provided for use in indicating erasure and editing of data. The standard system displays forty characters per line, and either thirteen or twenty-six lines, with a display area of 6½″ × 8½″. The character set includes capital letters, digits, and twenty-six special symbols and punctuation marks. A computer-telephone line control unit costs about $11,000, and the control unit between the terminal and the 2,400 bits/sec line, about $5,000. As usual, data sets (201 series) are required at each end of the telephone line. Up to ten display consoles can be located up to two thousand feet from the control unit. The console price varies from $4,000 to $6,000 depending on capability. A printer costs an additional $3,400.

9. *The Control Data Corporation (CDC) 210 Computer Inquiry and Retrieval System*

This is another system designed for business use, which is, however, potentially useful in CAL. Its basic unit is a 211 Entry-Display Station, consisting of a table top keyboard and CRT display. Twenty lines of fifty characters each may be displayed on the 6″ × 8″ screen, with the characters including the usual alphanumeric repertoire plus special characters to meet specific user needs. An index marker (cursor) can be controlled by the operator to correct mistakes and otherwise edit a message before it is transmitted to the computer. A printer can be attached to the 211 station to provide hard copy of any information displayed on the CRT.

Up to sixty-three display stations and forty printer stations may be connected to a 3290 Central Control Unit. This control unit is then connected to the central computer via 201 series data set, telephone line (2,400 bits/sec), and an interface unit appropriate to the particular computer being used.

Approximate costs of components of a 210 system are as follows:

211 Entry and Display Station	$81/month
3290 Inquiry and Retrieval Controller for the 210 system	$557/month
218 Printer Output Station (IBM Selectric typewriter, 15.5 characters/sec)	$130/month

10. *UNIVAC 1004 and 1005 Systems*

These units are actually small computers with arithmetic and editing capabilities, and a small amount of core memory. Rental prices range from $1,150–$1,750/month, with purchase prices from $46,000–$74,500. The adapter connections for peripheral card reader or punch, magnetic tape, or typewriter cost $200–$600/month additional.

Each 1004 or 1005 system is interfaced to a data set and a 2,000 or 2,400 bits/sec line by a device called a Dead Line Terminal, renting for $200–$290/month. The data set at the computer end of the telephone line connects to a Communication Terminal Module, renting at $60–90/month depending on data rate. If several terminals are used, up to sixteen of them may be connected to the central computer through a multiplexing Controller unit, costing $650/month, and up to sixty-four terminals may be connected through more expensive control units.

These systems were designed for business applications and would require some modification to be suitable for the typical scientific or instructional dialogue use.

11. *Scientific Data Systems, Inc. (SDS)*

The model 9437 keyboard-printer can be located remotely from any SDS computer, using full duplex 2,400 bits/sec transmission lines and a coupler (interface) which can accommodate up to three keyboard-printers. This equipment is similar to the Teletype Model 35 ASR. SDS also has a CRT display system with optional character generator, vector generator, and light pen.

12. *Sanders Associates Remote Terminal Devices*

Sanders Associates has just announced a new series of display systems incorporating alphanumeric keyboards and CRTs which display up to 1,000 characters on a vertical 8½″ x 11″ printed format. The model 710 is a basic information retrieval terminal; the 720 has a variety of editing capabilities; the 740 adds vector capability and light pen. The latter would probably require wide-band communication links.

Medium Data Rate Devices

We shall rather arbitrarily define the medium data rate to extend from just above the maximum conditioned voice grade line rate (roughly 3,000 to 4,000 bits/sec) up through the lowest-frequency TELPAK service—TELPAK A at 40,800 bits/sec. While some of the devices described below might operate at lower rates, this is not usually desirable, because performance deteriorates too severely. Some of the medium rate applications are possible because of the use of a small computer at the terminal. Without such logic available at the remote terminal, even higher-frequency data links would be required.

1. *IBM 2250 CRT Displays*

The IBM 2250 display is a versatile device that may include vector generation for graphic material, light pen, character generation, and a second keyboard for specially programmed display functions. This equipment must operate with its 2840 control unit close to the central facility. The 2250 may be located up to 2,000 cable feet from the 2840. A special feature may be obtained to allow the 2840 to be located up to one mile from the central computer, using a long line adapter and a 125 KHz bandwidth line. No area price is available at present for this feature. Distances over one mile are under consideration.

Common carrier links are also under consideration. However, at 2,400 bits/sec using voice grade lines and 201 series data sets, it is not likely that light pen tracking can be achieved. For this, wide-band service of at least TELPAK A (40.8 KHz) and very likely TELPAK D (up to 1 MHz) may be required. (These facilities are described more fully in Section III of this appendix.)

The 2250 display for a single unit with a full complement of graphical features may be estimated as follows:

2250 Display Unit	$350/month
Absolute Vectors	$225/month
Alphanumeric Keyboard	$ 50/month
8K Buffer Storage Unit	$400/month
Character Generator	$300/month
Light Pen	$ 75/month
Programmed Function Keyboard	$100/month
	$1500/month
2840 Control Unit (up to three 2250s using a multiplexor)	$1100/month
Vector Control Unit	$ 125/month
	$2725/month

Hence, three such 2250 units sharing the same 2840 would lease for $5725/month.

2. *Digital Equipment Corporation 338 Display*

The DEC 338 display is an interesting device because it indicates how one may obtain significant gains through the use of a small general-purpose computer as an integral part of the terminal. In this case, the PDP-8 computer is used with the DEC 340 display to provide an economical, flexible graphic display with modest communication link requirements.

This combination of equipment is able to perform display computations with a 1.6 microsecond cycle time to achieve a rate of 300,000 additions/sec while maintaining a flicker-free display of 15,000 points, 300 inches of vector, or 1,000 characters on a 9⅜″ square area.

The PDP-8 allows a reduction in data transmission because programming allows one to transmit changes in the display rather than entire pictures. Rotations of the display may be done at the terminal, again reducing the amount of data to be transferred. These features allow satisfactory operation with voice grade data links.

DEC prefers to sell its display at an approximate price of $50,000. However, leasing arrangements can be made at about $1,250–$1,500/month, depending upon actual equipment selected and negotiation with the company.

3. *Philco READ System*

The Real-time Electronic Access Display system (READ) is a CRT, keyboard, and light pen capable of textual, tabular, and annotated graphical formats. Information can be viewed directly on the face of the CRT, projected on a wall screen, recorded on 16 or 35 mm film, or reproduced on paper by a Xerox recorder. It displays over 4,000 characters or 2,000 lines which are refreshed thirty times per second. Screen sizes are available from 9″ to 24″. Characters can be defined by the user.

4. *Control Data Corporation Digigraphic System 270*

The CDC Digigraphic System is a light pen console system which is actually designed for use within a few hundred feet of a CDC 3200 computer. In this sense, it is not a true "remote" terminal system, although it may be possible to modify the CDC system to permit linking of the consoles to the control unit or the control unit to the computer by wide-band communication lines.

The 273 Digigraphic console contains a 22-inch diameter CRT, a light pen, and a 25-key keyboard. By suitably programming the computer, the keys are assigned to perform specific, frequently-required functions. The surface of the CRT is divided into a working surface—an 11″ × 17″ or 14″ × 14″ rectangle—and a control surface, defined as the area outside the working surface. Graphic displays are formed and the light pen is used to enter graphic information within the working surface. Light buttons,[3] light registers,[4] and alphanumeric information can be displayed on the control surface.

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[3] Light buttons function in much the same way as programmed keys on the keyboard, except that they are "depressed" and their programs initiated with the light pen rather than with the finger.

[4] Light registers permit the user to enter certain special kinds of alphanumeric information into the computer by writing with the light pen.

The basic function of the Digigraphic System is to permit graphic communication between man and machine. The user can enter information into the computer by sketching or by specifying end points of lines, vertices of polygons, centers and radii of circles, etc., with the light pen. He can then cause the computer to operate on this information in a programmed way and display the results.

A standard 270 Digigraphic System consists of a 271 Controller Unit, a 275 buffer memory, and one 273 console, all leasing for $5,500/month. Up to three 273 consoles can be used in each system, each located up to 200 feet from the 271 Controller. The CDC 3200 computer, a medium-size, general-purpose computer which is a necessary part of the 270 Digigraphic System and which may be time-shared, leases for $10,000–$12,000/month.

High Data Rate Devices

These devices require very expensive transmission lines even for short distances. If real-time direct transfer is required, multiple TELPAK lines may be employed. For very large bandwidth, microwave circuits may be used. In most cases, however, it is far more economical to use a small computer buffer.

Devices falling in this category are:

- Direct drive CRT displays;
- Core-to-core transfers;
- High performance magnetic tape;
- Intermediate storage to and from core;
- High-speed analog-to-digital and digital-to-analog equipment.

Devices in this category typically operate from 50,000 bits/sec upward. Common carrier communication channels in this bandwidth are available up to and including the 10 MHz used for color television.

Process Communication and Control Devices

These devices are used for such purposes as controlling a laboratory or manufacturing process, feeding information into the process and/or extracting data from it, analyzing the data, and feeding it back and/or displaying the results. Such equipment probably will not be as useful for instructional purposes as that described above, but it may have some applications to undergraduate laboratory situations. For instance, a process controller might be used to program a sequence of operations on an oscilloscope for the purpose of instructing a student in how to use such an instrument. A laboratory experiment which requires an isolated environment could be carried out by means of a process controller, eliminating possible hazards or disturbing influences from direct manipulation of the apparatus. At a more advanced level, such equipment would also make it possible for students to gain experience in sophisticated techniques of equipment control and data analysis.

To provide a general idea of what process control terminals do and how much they cost, a few examples are described below.

1. *IBM 1070 Process Communication System*

This terminal system is designed to provide a means for carrying out laboratory experiments under the control of the central computing facility at fairly low cost. In addition to the 1070 system configuration designed to meet particular laboratory needs, this equipment requires a voice grade line (an ordinary telephone circuit is adequate) and data set.

There are two models available with the ability to provide two different rates of data transmission. The 1071–2 terminal control unit operates at 66.6 characters/sec and leases for $170/month. The 1071–2 also requires a more expensive data set (202 series at $40/month).

Studies are being conducted to determine whether the 1071–1 may use the same data set as the 1050, but the price range is essentially correct if one assumes the 103 series data set at $25/month.

The 1071 may be attached to a variety of devices such as:

1072 Multiplexor and Terminal Unit. (Provides terminal posts and switching relays for up to fifty process signals. Up to six 1072s may be combined in one terminal station.)	$10/month
1073 Terminal Unit (controls opening and closing of up to fifty switches to operate laboratory devices).	$15/month
1074 Binary Display (ten light pairs).	$30/month
1075 Digital Display (up to eight digits).	$60/month
1076 Manual Binary Input (ten on/off switches to signal process information).	$25/month
1077 Manual Decimal Input (six ten-position rotary switches to enter decimal data values).	$25/month

1053 Alphanumeric Printer (to print output and display operator instructions).	$50/month
1071 Analog–Digital Conversion. (Converts high level analog voltages [−1 to +5 volts full scale] to three BCD [binary–coded decimal] character representations for transmission to central facility. Conversion time is 16.7 milliseconds/sample.)	$65/month

Other features available include thermocouple reference blocks, digital pulse converters, digital pulse counters, and many other similar devices.

Consideration is being given to features to allow keyboard–printer and digital–to–analog conversion. Without a keyboard, some independent way must be used to alert the central computing facility that a 1070 station wishes to log on. As mentioned earlier, a touch–tone telephone might suffice.

Because the terminal configuration is so dependent upon the needs of a particular experiment or process, it is almost impossible to give accurate general price estimates. However, a rather minimal terminal may be estimated at about $250/month, a fairly sophisticated terminal at $550/month, and a fairly typical experiment setup at $350/month.

The use of this equipment would allow low data rate instrumentation of many experiments in which the logical power of the central computing facility may be applied. Data may be collected and analyzed, and the computer may initiate actions to manipulate and control the experiment.

2. *IBM 1800 Data Acquisition and Control System*

This is a versatile laboratory terminal with the logical capability of a small computer and a wide variety of digital input and output terminals, analog–to–digital (A–D) and analog terminals, and many other valuable features for conducting experiments requiring more precision and higher data acquisition rates than are possible with the 1070. In addition, a variety of peripheral equipment is available for data logging and display at the terminal location. Wide–band communication lines are necessary to link this system with a large central computer.

The 1800 Process Controller unit is available with either two or four microsecond memory in sizes from 8K (8,000) to 64K (64,000) bytes (eight–bit words). The lease price for the 8K–four microsecond machine is $1,165/month, while the 64K–two microsecond machine is $3,250/month.

Because of the extreme versatility of the equipment, complete 1800 systems can be configured in a large number of ways. This unusual flexibility makes it difficult to give realistic area prices for a system. Several study configurations indicate that a fairly sophisticated terminal will lease for $3,000–$5,000/month. As an example, the following system was configured at about $3,000/month:

Paper tape I/O;
Keyboard–printer;
2315 disk storage unit (for data logging);
Interface with IBM system/360 central computer;
96 bits of digital voltage level input;
80 bits of digital pulse output;
32 points of analog input with comparator and ±10 mV, +50 mV, and ± 200 mV amplifiers, as well as high–level inputs;
16 process interrupts (terminals through which switching signals from the process can be fed into the control unit);
8K–four microsecond process controller unit.

3. *DEC PDP–8 Process Control Terminal System*

The versatile, relatively low–cost PDP–8 is a nucleus around which one may construct a flexible laboratory terminal. The basic PDP–8 consists of a 4096 twelve–bit word memory, console, typewriter, paper tape reader and punch, and I/O console. To this one may add A–D converters, digital contact sensing and operation systems, data set linkage, D–A converters, and so on, to form the desired laboratory terminal. Once again, it is difficult to estimate the system cost in general. The basic PDP–8 sells for $18,000, and sample system studies indicate a total system terminal with capacity for:

Data set communication with central facility,
12 independently–buffered D–A conversions (11 bit plus sign),
12 multiplexed A–D conversions (11 bit plus sign),
96 relay contact interrogations, and
96 relay contact outputs

at a price of about $54,000. While DEC prefers not to lease, an approximate figure of $1,200/month is estimated. Maintenance charges are $200/month. In addition, a wide–band communication link with a central computer is necessary.

It is to be emphasized that the use of a small computer as a part of the terminal is essential in many laboratory situations. By having the computer act as a digital filter as well as a process controller, it is possible to reduce the requirements for communication channels to the central facility to more reasonable levels. The inherent advantages of central facility support for the laboratory experiment is retained and enhanced in this way. The central facility functions in the most vital role of analysis and overall control, with the terminal able to execute these commands on site.

III. COMMUNICATION LINKS

After having determined the terminal needs, the next problem is the transmission of data to the central facility from the terminal, and the receipt of signals from the central facility to control the terminal devices. As indicated earlier, this transmission may take place at a variety of data rates. The lowest–cost communication links are those with relatively low data rates, and are classified as voice grade or teletype service. Such service is limited to data rates of less than 3,000 bits/sec or so and includes the various kinds of ordinary telephone and teletype service, plus private leased–line facilities and Western Union's Broadband Exchange Service (BXS). This latter service is (or will soon be) capable of transmission rates in excess of a few thousand bits/sec. For data rates up to 10^6 bits/sec, wide–band TELPAK leased lines seem to be the only common carrier service available.

Just as computers and terminal devices are undergoing development causing a very fluid price structure, so communication lines and data sets are being improved at a rapid pace. The cost figures quoted in this section were applicable to The University of Michigan and southeastern Michigan as of the spring of 1966. And just as computer engineers must be consulted in the design of remote terminal systems and central computing facilities, communications engineers from the telephone company or Western Union must be consulted to obtain an efficient and effective design and accurate cost information for communication links. The truth of these warnings has been indelibly impressed upon those of us involved in collecting information for this appendix, and for the section on communication links in particular.

However, the prices mentioned in this section should provide the reader with a general idea of the amount of money involved in tying a terminal to a computer located some distance away. In cases where the rates of two common carriers (AT&T and Western Union) are compared, any differences may be temporary or apparent, rather than real. Fast developing technology has caused rates to change rapidly, and in many cases it has been difficult to insure that devices and facilities with identical features and capabilities are being compared. The companies themselves must be contacted for official, up–to–date cost and information.

Teletype and Voice Grade Lines

This category of communication service may be sub–classified into circuits which are limited to reliable data rates of less than 2,000 bits/sec (the ordinary teletype and telephone services), and those which permit reliable data transmission at rates up to 3,000 bits/sec or so (Broadband Exchange Service and specially conditioned leased lines). In particular, communication links in this latter group are necessary for the many terminal devices which require data transmission at 2,400 bits/sec.

In general, leased private lines are more reliable than dialable circuits, because they are conditioned and guaranteed to provide a certain level of service. However, those dialable or switched circuits designed for data transmission may be more satisfactory in this respect than telephone lines, which are intended for voice communication. Western Union's Broadband Exchange Service, for instance, employs a combination of four–wire circuits for short distances and microwave relay transmission over long distances, and has been engineered to minimize noise, crosstalk, and distortion which interfere with reliable data transmission. Nevertheless, several of the terminals described in Section II above can and do operate satisfactorily over ordinary telephone circuits. Sometimes the particular circuit obtained by dialing may happen to be noisy, preventing reliable transmission. In such cases, the computer may be dialed repeatedly until a noise–free circuit is obtained, and charges for the noisy connections may be deleted by the telephone operator.

1. *Teletype and Voice Grade Circuits Limited to Data Rates Less Than 2,000 bits/sec*

Of the five kinds of service described in this category, the first two (teletype exchange and telephone services) involve message charges based on the number and length of messages. Since the other services described (private wire teletype, WATS, and foreign exchange) do not require message charges, any comparison of costs must take into account the amount and type of use. If very heavy use is to be made of the communication link, for instance, the teletype exchange service, which appears to be the least expensive of the five services described, could turn out to be considerably more costly than the most expensive wide area telephone service.

a. Teletype exchange services

If teletypewriters are used as terminals, one of the dialable teletype exchange services may be used at lower cost than ordinary telephone service. The nationwide TWX (AT&T) and Telex (Western Union) networks can be used in much the same fashion as the long distance telephone network. Voice communication between the remote user and the computer is not possible over these networks. Although the data rate is low, this may not be a serious disadvantage in many instructional or research situations.

In the Telex service, the rate for a one-minute message between Ann Arbor and New York City is $.30. There is no minimum message length, and there is a 40% discount on monthly charges in excess of $87.50. AT&T's TWX service assesses charges on the same basis as long distance telephone calls. The rates are somewhat lower than long distance rates, but the minimum three-minute message is charged for and there is no quantity discount. Therefore, in some cases TWX may be more expensive than Telex. However, an accurate comparison of costs again requires a careful investigation of the kind of use to be made of the communications facilities.

b. Local telephone service

Basic line charges in The University of Michigan Centrex system are $8.75/month for a line to the central office, including a telephone. Special features for the instrument are, of course, extra. For example, the touch-tone feature mentioned in Section II costs an additional $1.00/month. If the data set is to be placed on an extension of an existing line, the extension is $3.50/month. But in this case, an exclusion feature at $.25/month is required to prevent interference in data transmission from the other telephone.

If it is not possible to install a telephone within a Centrex system, the facility may be installed on a business phone, which rents at a basic price of $9.05/month in Ann Arbor, Michigan.

As with ordinary business telephones, local data connections are available without limit at the standard monthly charge, and long distance data connections cost the same as long distance telephone calls. Because of the message charge, extensive use of the long distance telephone network can be expensive.

c. Private wire leased teleprinter lines

In a low data rate system involving heavy traffic between fixed locations, a leased teletype line may be more economical than exchange service with its message charges. Such lines may be leased from AT&T or Western Union at identical rates. The basic interstate mileage charge for leased teletype lines is $1.10/mile/month for the first 250 miles, decreasing in three steps to $.385/mile/month for distances beyond 1,000 miles. Intrastate rates vary from state to state, but in Michigan they run about twice the interstate rate.

The basic line will carry up to 56 bits/sec from a standard 75 words/min (wpm) teletypewriter operating with a five-level character code (five information

PRIVATE WIRE LEASED TELEPRINTER LINES
COSTS PER MONTH

	HALF DUPLEX			
	45 and 56 bits/sec (5-level code, 60 and 70 wpm)	**75 bits/sec (5-level code, 100 wpm)**	**150 bits/sec (ASCII code, 100 wpm, and IBM 1050)**	**FULL DUPLEX**
Line cost,				
1st 250 mi	**$ 1.10/mi**	**$ 1.21/mi**	**$ 1.375/mi**	**Add 10%**
over 1000 mi	**0.385/mi**	**0.424/mi**	**0.481/mi**	**Add 10%**
Channel termination[a]	**12.50**	**13.75**	**15.625**	**Add 10%**
Local circuit[a]	**6.70**	**7.37**	**8.375**	**Multiply by 2**

[a] **These charges apply at *each* end of the line.**

bits plus one start and 1.4 stop bits/character). Conditioning the line for 100 wpm in the five–level character code (75 bits/sec) adds 10% to the cost. Private lines conditioned for 150 bits/sec have recently become available as a standard item, and lease for 25% more than the basic line rate quoted above. Such lines will handle the 110 bits/sec rate of Model 33 and 35 teletypewriters using the ASCII code at 100 WPM, as well as the 14.8 characters/sec rate of the IBM 1050 terminals used in the COURSEWRITER system. An additional 10% is added for full duplex facilities, permitting simultaneous send–and–receive.

To these line charges must be added channel termination and local circuit charges at *each* end of the line. These, together with the line costs described above, are summarized in the table on p. 40.

d. Wide area telephone service (WATS)

Wide area telephone service permits the user to dial any telephone or computer installation within a specified area for a flat monthly rental. The rates quoted here for this service are those for a user in Ann Arbor, Michigan, and are given merely to provide a rough idea of the costs involved.

(i) Intra–state WATS service charges.

Entire state of Michigan (Area codes 313, 517, 616, 906)	$700/month
Eastern lower peninsula (Area codes 313, 517)	$400/month
Southeastern Michigan (Area code 313)	$300/month

(ii) Interstate WATS service from Ann Arbor.

Zone 4 (extending from east coast to rocky mountain states, except Florida and Michigan)	$1,400/month[5]
Zone 6(continental United States except Michigan)	$2,050/month[6]

A recently-developed modification of WATS is IN-WATS, which permits a subscriber to receive incoming calls from a specified geographical area at a flat monthly rate. This service is not yet available on a nationwide basis, although it probably will be in the near future. The charges are the same as those for WATS.

e. Foreign exchange service

This type of service in effect places the user's telephone in a remotely–located exchange area. For instance, if extensive communication were required between the Commision on College Physics office in Ann Arbor and various telephones and computer installations in the metropolitan Detroit area, then foreign exchange service would permit CCP to dial as if its telephone were located in Detroit rather than in Ann Arbor. Data connections to installations in the Detroit exchange area would be available without limit at a flat monthly rate. Between Ann Arbor and Detroit (a distance of about forty miles), this service would cost $163/month. Foreign exchange service between Ann Arbor and New York City (a distance of

	WESTERN UNION PWS		AT&T	
	Half Duplex	Full Duplex	Half Duplex	Full Duplex
Mileage rate interstate	$ 2.02	$ 2.22	$ 2.02	$ 2.22
Mileage rate intrastate[a]	No tariffs filed; about same as AT&T		4.25	4.68
Channel termination charge[b]	12.50	13.75	12.50[d]	13.75
Local circuit charge[b]	10.00	18.25	12.50[d]	13.75
Conditioning charge[b, c]				
1,200 bits/sec	20.00	20.00	None	None
2,400 bits/sec	47.50	47.50	37.50	37.50

[a] **In Michigan.**

[b] **Applies to *each* end of communication line. Total cost for a system is therefore twice the figure given.**

[c] **Includes high-level transmission filters and driver amplifiers.**

[d] **For lines over 25 miles in length. Cost is $7.50/month plus $5.00/month/additional station on circuits shorter than 25 miles.**

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[5] or ($415 + $24/hr for each hour over 15 hrs)/month

[6] or ($540 + $30.50/hr for each hour over 15 hrs)/month

515 miles), costs about $980/month. This service is generally less expensive than WATS, but more costly than a point–to–point leased line, reflecting the fact that it is intermediate in scope and flexibility between these other services.

2. *Voice Grade Circuits for Data Rates up to about 3,000 bits/sec*

a. Private leased lines

Leased lines are point–to–point, telephone–to–telephone, or switchboard–to–switchboard connections, always at the disposal of the user. The significant advantage they posses over dialable circuits is that bandwidth and freedom from noise can be guaranteed by the leasor.

If several voice grade channels are used extensively between two points, it may be economical to lease a wide–band line for multichannel voice grade transmission. A 48 KHz TELPAK A line, for example, can carry twelve 2,400 bits/sec full voice grade channels (see the section on wide–band facilities below).

The *monthly* cost of a private line leased from Western Union or AT&T can be estimated from the table on p. 41.

b. Western Union Broadband Exchange Service (BXS)

Western Union has developed a flexible and versatile switched circuit system for data transmission called the Broadband Exchange Service. BXS subscribers can dial other stations in their system in the same way they use the long distance telephone; they can also dial the class of service (data rate) they need for a particular purpose. Line charges are billed on the basis of duration and distance of call, and class of service selected. At present, customers may subscribe to Schedule I service (so-called 2KHz service), and to Schedule II service (4 KHz or 2 KHz service, selected by the user for each call). The 2 KHz bandwidth accommodates a data rate of 600 bits/sec, while 1,200 and 2,400 bits/sec require the 4 KHz bandwidth. It is anticipated that bandwidths of 8KHz, 16 KHz, and 48 KHz will be added in the near future. BXS provides full duplex (simultaneous send and receive) facilities at all data rates, and permits users either to communicate by voice or to transmit and receive data in digital or analog form. The system is designed with four–wire circuits and special switching gear to minimize the noise, distortion, and crosstalk which can interfere with reliable data transmission.

Typical metered line charges for BXS are, per minute,

	2 KHz Service	4 KHz Service
Detroit–New York	$.30	$.35
Detroit–Los Angeles	.55	.65
Between any two points in Michigan		.20

A minimum usage charge for one minute applies on each completed call or data connection. Beyond the first minute, fractional minutes are charged for in tenths of minutes. These rates apply within the limits of cities with Class I Western Union telegraph offices (this includes most cities of over 25,000 population). PWS (private wire service) lines must be leased to serve any locations outside of such cities. In addition to the line charges, there are certain non–recurrent and monthly charges for the communications equipment required to use BXS. These are summarized in the table below.

3. *Data Sets for Voice Grade Service*

The data sets to be used with common carrier lines depend for their designation upon whether the line is a dialable line or a leased line, and whether the code is presented in serial or parallel fashion. The

	Non-recurring installation charge	Fixed monthly service and equipment charges
Broadband service (including local channel facility, telephone instrument, and association subset):		
Schedule I service (2 KHz)	**$25.00**	**$15.00**
Schedule II service (4 KHz and 2 KHz)	**25.00**	**30.00**
Data set (for modulation/demodulation of signals, serial bit–by–bit transmission):		
Schedule I service		
0–600 bits/sec, asynchronous	**25.00**	**27.00**
Schedule II service		
0–1,200 bits/sec, asynchronous	**25.00**	**27.00**
0–2,400 bits/sec, asynchronous	**50.00**	**42.00**
2,400 bits/sec, synchronous	**50.00**	**72.00**
Circuit extensions beyond city limits:		
Channel conditioning charge	**10.00**	**10.00**
Rate per mile	**....**	**2.22**

following table is a summary of the most popular Bell System data sets likely to be found in voice grade service at the central facility. Prices of these are fairly stable, but new kinds of data sets are currently being developed, especially for use with large central computing facilities. Prices of Western Union data sets are comparable, as may be seen from the above table of charges for BXS equipment.

Data Set Series	Data Rate (bits/sec)	Lease Price
101, 105	110	$25/month
103	134.5	$25/month
202	0–1,200	$40/month
201	2,000 or 2,400 (synchronous)	$70/month

Wide–Band Transmission Facilities

Wide–band facilities are those permitting data rates greater than 3,000 or 4,000 bits/sec. Although Western Union's Broadband Exchange Service described above may soon become available at these higher data rates, the only services now commercially available are the TELPAK facilities. These can be leased from AT&T or Western Union at identical mileage rates. Facilities exist to transmit signals with a bandwidth (data rate) greater than the 1 MHz of the highest grade TELPAK service. However, these video bandwidth channels are so expensive and so unlikely to find application to CAL in the immediate future that they will not be discussed here.

In addition to the line rental and data set costs described below, there will be various charges for channel terminations and necessary local facilities and circuits at either end of the TELPAK line. Since these will depend on the particular application, and since the mileage and data set costs usually will be very much larger, no attempt has been made to summarize these additional items.

1. *Line Rental Charges*

At the present time, four grades of TELPAK service are available as shown in the following table.

Service	Bandwidth (or data rate in bits/sec)	Interstate Rate/Mile/ Month
A	48 KHz	$15
B	96 KHz	$20
C	240 KHz	$25
D	1 MHz	$45

TELPAK A service between Ann Arbor and New York City, for instance, would cost $7,725/month. With the possible exception of TELPAK A, these lines are usually engineered to meet the special needs of the user. Therefore, the rates are only approximate.

2. *Data Sets for Wide–Band Transmission*

With the exception of TELPAK A service, data sets for wide–band transmission are special devices designed for a particular purpose. For TELPAK A service, the 301 series data sets are available to operate at 40.8 kilocycles synchronous transmission rate. These devices rent for $250/month, and one such device is required at each end of the TELPAK A line.

The data sets for TELPAK B, C, and D service require engineering design for each application. However, order of magnitude estimates may be given for TELPAK C data sets at $550/month/terminal, and for TELPAK D data sets at about $1,300/month/terminal.

There are, obviously, some applications which can only be served adequately through wide–band facilities. But the foregoing should indicate the importance of careful study of each application in order to realize the most economical trade between bandwidth and the logical capability of the terminal device. As indicated earlier, the use of a small computer at the terminal may frequently reduce the bandwidth requirements of the communication line to voice grade service, where otherwise wide–band facilities would be required.

IV. THE VIDEOFILE[7] SYSTEM

The development of video tape recorders has made it possible to devise automated systems for the storage, retrieval, display, and duplication of printed matter and other documents using magnetic tape. The only system of this kind on the market at present is the elaborate and highly flexible Videofile system made by the Ampex Corporation. Videofile units could be included in a CAL network to display visual information to the student, accomplishing the same function as the automatic slide projectors mounted in modified IBM 1050 terminals.

Briefly, the Videofile system enables a document or microfilm frame to be recorded on magnetic tape along with an identification code. The tape then can be scanned automatically to find any given stored document by feeding the appropriate code into the system. Requests for a document can be made from a local or remote station with a telephone dial, a keyboard, or a card reader, or by a central computer. Typically, 259,200 documents originally 8½" x 11" can be stored on a fourteen-inch diameter, 7,200-foot reel of two-inch magnetic tape; the average access time to retrieve any of these documents from the tape is 115 seconds. (For a five-inch reel of tape holding 10,800 pages, the average access time is only eleven seconds.) Images are recorded on the tape from a video camera or a microfilm attachment, and may be displayed as a refreshed TV image on a CRT or printed on a facsimile device. The usual CRT-TV display requires a wide-band, coaxial transmission line between the tape unit and the display station, whereas the facsimile reproducer can operate over voice grade telephone lines. Slow-scan television transmission can also be used to transmit an image over voice grade lines to a CRT station at a rate of 80 sec/page.

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[7] Trade Mark, Ampex Corporation

There are at least two ways in which Videofile could be incorporated into a CAL system involving remote terminals without requiring wide-band transmission facilities. A Videofile system located at the site of the central computer could send images of documents (graphs, text, illustrations, etc.) to the appropriate remote terminals upon request from the instructional program stored in the computer. The image of the document would appear on a CRT at the remote terminal as a slow-scan TV picture. (The picture is formed from top to bottom of the screen, so that if text is involved, the student can begin reading before the image is completely formed.) The Videofile system can be time-shared just as is the central computer.

A second possibility is to locate the Videofile unit in a classroom or building housing many instructional terminals and remote from the central computer. Requests for visual information can be transmitted from the instructional program in the computer over a voice grade line to the Videofile. TV pictures from the video tape recorder can then be distributed over inexpensive runs of coaxial cable to the appropriate nearby instructional terminal. Such an arrangement would be economical only when a large number of remote terminals could be located near each other and near the Videofile system.

A basic Videofile system designed for a particular purpose can be purchased for about $200,000—a *very* approximate price. The system as it now exists, however, is probably larger, more flexible, and perhaps more sophisticated than necessary for use with CAL. As the systems come into more widespread use, as technological improvements are made, and as other manufacturers enter the field, prices will probably decrease substantially. The Ampex Corporation is currently developing smaller, less expensive versions of their system.

appendix c

Linguistic Mode Physics Programs

The programs described here are representative of physics programs prepared to date for use in an instructional format. Most were prepared in Seattle during summer of 1965 at the Working Conference on New Instructional Materials held at the University of Washington, and all were programmed in IBM's COURSEWRITER language. Although several have not yet been debugged and none have been rigorously tested, these programs nevertheless indicate some of the ways physicists have attempted to use the computer as a teaching tool within the present course structure. We emphasize here that these materials are at best first efforts which may guide others seeking to develop new auxiliary tools for physics teaching.

GEOMETRICAL OPTICS UNIT

(T. R. Palfrey—Victor Cook—Robert Dough—Michael Brady)

This is a self-taught instructional unit (i.e., no instructor is available to the student for this material) prepared for use at Stony Brook during spring 1966. It consists of assistance on problems and laboratory work and an examination, of which only the examination is *required* of the student. Help on problems and laboratory work is optional. The work is keyed to Chapters 26 and 27 of *The Feynman Lectures on Physics*, Volume I.

In working problems, the student requests help by problem number and is interrogated by the computer. He may be asked if he has read the appropriate sections of the text; he may be asked about definitions, sign conventions, or about his results for parts of the problem. The terminal will normally provide help in the following forms: by presenting a slide sketch of the physical situation, by reference to the text, by suggesting that the student work another problem first, or, in unusual cases, by supplying a needed piece of information.

Computer assistance on the lab is designed to help students perform the experiments, should they feel they need help, and to reinforce them, should they need assurance that what they have done is correct.

The examination is divided into three parts. Part I involves the construction of a piece of optical apparatus and the measurement of its properties. The student is given a kit of lenses, etc., and an optical bench. He is told to build an instrument (six different versions of Part I have been prepared) that meets certain specifications (for example, a non-inverting "projector" consisting of two lenses, such that the object-to-projected-image distance be the length of the optical bench, and the object-to-second-lens distance be as short as possible). He is asked to measure properties of the finished device. When he has measured the suggested parameters, he signs onto the terminal and answers questions about the device he has built. The terminal may accept his answers, or may decide that his measurements were too sloppy, or that his device could not have worked as specified. Instructions and hints from the terminal then guide the student (at a cost in examination score) toward a good design. When the design and measurements meet the standards required, the student proceeds to Part II of the exam.

Part II consists of one or two questions designed to find out if the student either understands the functioning of the device he has built, or can figure it out. These are ordinary pencil and paper problems. For each Part I there are three alternative Part IIs. The possibility exists that the student could report his results on Part II to the terminal, which could then grade his result.

Part III, of which about six versions are planned, will consist of one or two more conventional questions. At least one of the problems will probably involve application of Fermat's principle, which is emphasized in Feynman.

DEMO–2

(Everett M. Hafner)

This program was written for the IBM 1440 using terminals in Ann Arbor and Seattle. Its central idea is the introduction of a variety of topics in physics, at different levels of difficulty, using the style of an oral exam. The aim is not to teach the subject, but to reveal quickly a student's range of knowledge, grasp of fundamentals, and ability to deal with unusual problems. We list below the principal labels of demo–2, with brief descriptions of the material under each label.

start

First label. Gives the option of transferring either to "instructor" or to "student."

instructor

Describes material and reveals principal labels, thus providing the option of beginning at any of several points.

student

Explains that material will be presented in sequence, but that any topic may be skipped. Does not reveal labels.

exh2

Raises the question of the time required for a particle to fall to earth from the distance of the moon. Leads the student to the order of magnitude, and then to a good calculation from Kepler's Third Law. An interesting feature of this question is that the correct answer can be obtained by an entirely wrong method involving two compensating errors: taking the period to be equal to the calendar month, and assuming that the average speed of fall is equal to the orbital speed. Discusses the accuracy of the correct method, and tests the student's mastery of the method by raising similar questions about planetary orbits.

exh1

A brief quiz on the fundamental interactions and the classes of strongly interacting particles. Asks for the names of the interactions and the order of their strengths; requires no quantitative knowledge.

e5

Asks for the numerical values of ten widely used physical constants, accepting all responses that are correct to two significant figures. Scores the student and sends him back if less than five are correct.

begin

A problem in elementary mechanics, dealing with forces and torques on an accelerating rigid body. Seeks the condition for which a tipped cube, sliding with friction on one edge, does not rotate. Students frequently make the error of assuming that torques can be taken about an edge; when they do, they are led to see that the result is unreasonable, and are then guided through a correct treatment.

timing

Deals with transformation of the Coulomb force to a moving coordinate system, and reveals a relativistic discrepancy between what appears to be a correct result and the general law for transformation of forces. Asks the student to identify the source of the discrepancy.

The sample also contains, under the label "writer," a guessing game for COURSEWRITER authors. One discovers the flow of a program by guessing and trying a set of "ca" and "wa" statements. The game is designed to give rapid experience with the logic of COURSEWRITER op codes.

Comment

Each part of demo–2 is an attempt to explore a special direction along which programmed tests can go. Thus, the problem in Kepler's Laws probes a student's intuition; the quiz on terminology tests his familiarity with names, while the list of constants tries his knowledge of numbers and units; the mechanics problem exposes a common misunderstanding of rigid body motion; and the relativity dialogue is an attempt to raise, without completely answering, a provocative question which he may wish to pursue further. The model on which the sample is based is the typical qualifying oral exam, in which these aspects of a student's approach to physics come under scrutiny. Passing quickly from topic to topic, we attempt to evaluate his entire state of knowledge on the basis of very little evidence.

Even from this limited point of view, the sample in its current form needs improvement. Especially in the mechanics problem, where the need for matching formulas is inevitable, students bog down in symbolic difficulties that have no bearing on their knowledge of physics. Since little attempt is made to time and score the student within the program, his work must be read by an instructor. We are hard on the man whose approach to things is very different from ours. And the value of some of the material, for purposes of testing, depends on its novelty. In order to be of any use, the test would have to contain much more material, selecting at random the set that each student encounters.

"VEL"

(Everett M. Hafner)

The label "vel" under course Seattle 2 in the 1440 CAI system is a brief diagnostic exercise on the concept of instantaneous velocity. It seeks to discover, through a sequence of increasingly difficult questions, the status of a student's understanding of the concept. Principal points and branches in the flow diagram are as follows:

1. Write a definition. (The program does not examine this response; it is for information only.)
2. If we know (x_1, t_1) and (x_2, t_2) for a particle in motion on x, do we know $\underline{v}(t_1)$ or $\underline{v}(t_2)$?
   (no) br 3
   (yes) br 2a
   - 2a. Would we know $\underline{v}(t_1)$ if $\underline{v}$ were constant?
   (yes) br 2
   (no) br 2aa
   - 2aa. Numerical example of average velocity.
   (right) br 2
   (wrong) suggest sign off.
3. If we know (x_1, t_1), (x_2, t_2) and $\underline{v}(t_1)$, do we know $\underline{v}(t_2)$?
   (no) br 4
   (yes) br 3a
   - 3a. Special case; br 2 or sign off.
4. Concept of average velocity.
   (right) br 5
   (wrong) Case of uniform motion; br 5 or sign off.
5. Upper and lower bounds on $\underline{v}(t)$.
6. Do we know v at midpoint of time interval?
7. Mean value theorem.
8. Two particles with same (x_1, t_1) and (x_2, t_2). Same t($\bar{v}$)?
   (no) br 9
   (yes) br 8a
   - 8a. Draw some graphs. Is it clear?
   (yes) br 8b
   (no) suggest sign off.
   - 8b. Example of differentiation of x(t).
   (right) br 8c
   (wrong) suggest sign off.
   - 8c. Average velocity in example; br 8d or sign off.
   - 8d. What is t($\bar{v}$) in example? br 9 or sign off.
9. Is there a t such that $\underline{v}$ is same for both particles?
   (yes) Perhaps you guessed. br 10
   (no) br 9a
   - 9a. Do you understand? br 10 or br 9b.
   - 9b. Clarification. br 10 or sign off.
10. Number of intersections in (x, t).
11. Concept of derivative.
    (right) br 12
    (wrong) br 11a
    - 11a. Clarification. br 12 or sign off.
12. Do $\underline{u}(t)$ and $\underline{v}(t)$ intersect at t_1 and t_2?
13. What must they do?
14. Let's prove that they intersect. What about distances?
15. Common property of the two velocity graphs.
    (right) br 16
    (wrong) br 15a; clarification and br 16
16. So what must the curves do?
    (right) br 17
    (unclear) br 16a; clarification; br 16 or sign off.
17. What about the accelerations?
18. Is there an x such that $\underline{v}(t)$ is the same for both particles?
19. Proof.

Comment

1. The program contains many parts which proceed independently of response. Also, it does not incorporate scoring mechanisms. Therefore, it is only useful if the student record is examined by an instructor.
2. The emphasis of the program is on a working knowledge of concepts, not on formal definition. In a more satisfactory version, a nicer balance would have to be established between these two aspects of the subject.
3. In its present form, the program relies too heavily on yes–no responses, some of which are not followed up carefully. An expansion of such points might be worth the programming effort.

4. An inflexibility of viewpoint in this program (e.g., its insistence on graphical methods) may be unfair to some students. The central problem can be alternatively solved by an application of the mean value theorem to the difference of two functions. This alternative should perhaps be incorporated.
5. We deal here only with one–dimensional motion. Thus, the full vector nature of v is not explored. A supplementary section should be programmed with this objective in mind.
6. More generally, it is not yet clear that an approach of this kind can be truly diagnostic. If a student solves its problems easily, he probably has a good grasp of the concepts. But he may run into trouble for many reasons other than faulty fundamental knowledge. Only experience with the material, followed by extensive revision, can begin to throw light on the broad question.

WEIGHTLESSNESS

(Arnold Arons)

An instructional sequence rather than a diagnostic one, this program explores the subject of weightlessness through the example of a mass accelerated in an elevator. The program is constructed on a step–by–step, question–and–answer sequence which leads the student to understand the concept. The student is first checked on his qualitative understanding of the first and second laws of motion, and is then led to apply the second law to a body in an elevator and to extract a verbal interpretation of the algebraic results. He is next led through a description of his *sensations* of increasing and decreasing weight as he himself becomes the accelerated object, and is finally led to articulate what we mean by the term "sensation of weightlessness" in the condition of free fall:

The sequence has remedial branches, hints, and at one or two points suggests that the student sign off and return to the program only after studying some textual material on the laws of motion. The complete flow diagram, showing all of the statements in the program and their sequencing, folds out from the back cover of this report.

KINEMATICS

(Alfred Bork–Walter Michels–Karl Zinn)

This unit was first prepared as a printed program by Alfred Bork (Reed College) and Walter Michels (Bryn Mawr College). It has been adapted for computer presentation on the COURSEWRITER system by Karl Zinn (Center for Research on Learning and Teaching, The University of Michigan), but has not yet been completely debugged or tested on students.

The program is based on a strobe photograph of an object in non–uniform, two–dimensional motion, together with a table of time and position measurements made from the photograph. The student is asked five basic questions about these data:

1. In which interval of the strobe photograph is the velocity probably constant?
2. Are you certain it is constant in this interval?
3. In which interval(s) is the acceleration probably constant?
4. Write an algebraic expression to correctly represent the east component of position at the time t within the interval A to B of the motion.
5. What is the magnitude of the average velocity between the seventh and eighth seconds of the motion?

A student who answers each of these questions correctly sails through the program in a few minutes. If the student has difficulty, however, he is shunted into various remedial branches to try to overcome his difficulties. These remedial units include text displays, hints, and further questions to diagnose the difficulty and lead the student to understand the problem. Some of the remedial–diagnostic questions are centered around additional, simpler, one–dimensional strobe photographs.

As a printed program, this unit was rather inconvenient to use. Each student needed the entire bulky program, whether he used only five pages or fifty pages. Shuffling through this many pages to find the right one was not a satisfying occupation for many students. A tendency for students to become stuck in loops was also noted. By computerizing the program, these difficulties have been removed. However, it will require trial use with students to identify other problems which may arise.

appendix d

Four University-Based Systems[1]

I will describe here several computer systems that are not for sale anywhere, but that are used largely in universities. I chose these systems because I have seen them at least in partial operation and because at the present time they are being used in actual university or college courses . . .

The SOCRATES System

The first system is probably the lowest in cost . . . It's called the SOCRATES system at the University of Illinois in the Training Research Laboratory. This is Dr. L. H. Stolurow's concept . . . It consists basically of a modest computer in the 1600 series of IBM and an IBM 1710 control unit (i.e., a traffic manager) which allows students to communicate with the computer. The computer has a very small amount of high–speed memory; the auxiliary memory consists of a disk. The only means of getting information out of the computer is by cards or by outputting on the disk. The student station has a set of fifteen keys which the student uses to communicate his responses to the computer . . . It's largely meant to be used to select a response which would be of a multiple choice kind . . . .

Probably the most distinguished feature of this system is that you can load it with a large number (on the order of one to two thousand) of frames of visual display material–frames that have to be prepared in advance on filmstrips . . . . The intention is that there be a sufficient quantity and variety of these frames so that the student can be branched effectively by the computer program to what he needs, as a function of deficiencies exhibited by his responses on previous frames. The student sees these frames projected on a screen about ten inches square situated above his keyset. Another screen about half as large is used to display feedback messages to the student such as correct answer, incorrect answer, etc. The system is now set up to give instruction to fourteen students concurrently. It has a clock so that one can measure the amount of time it takes a student to make his response . . . . You can do some collection of data on the student's performance and put this out on the disk or on IBM cards for later analysis . . . .

They are now giving a course in symbolic logic with this computer . . . to 500 students . . . . The time Stolurow expects the average student will be taught via the computer is fifteen hours . . . this supposedly represents the equivalent of a full semester of coursework . . . .

The PLATO System[2]

The next system I'd like to talk about is the PLATO system, under the direction of Donald L. Bitzer, also at the University of Illinois. This one impressed me. It uses a CDC 1604 computer, but it's not time–shared in the sense that the PLATO system can share the machine with others who may, for instance, be compiling or computing at the same time. PLATO usurps the whole machine when it runs . . . . There are twenty student stations operating in one room . . . . It is actually being used for instruction in three courses: an electrical engineering course, a course in library science, and a course in clinical nursing.

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[1] This is an abstracted version of an invited speech to the Conference delivered by Joseph Rosenbaum of System Development Corporation's Educational and Training Staff. A full transcript of this speech is available from the Commission office.

[2] A more detailed description of PLATO is given in Appendix A.

A distinguishing feature of the PLATO system is that, on the TV display tube, you can superimpose graphic or keyboard material generated by the computer over fixed slide projector material. The slides are actually 35 mm film frames mounted on transparent plastic sheets. One hundred twenty–two of these frames can be mounted in the system at one time, and the student can type over the slide display with the keyboard, or the computer can generate graphic displays over the slide image . . . . The other nice feature is that you can edit the course material on–line from one of the stations without having to go through a complete compilation of the course . . . .

There is within PLATO a subsystem and a language called CATO . . . . It makes use of FORTRAN–type statements. You can express yourself, as a writer of a course, in CATO and the system will compile and get your material ready for presentation . . .

The Dartmouth System[3]

The third type of system in use today . . . is at Dartmouth . . . . They have attempted to introduce computers into the undergraduate curriculum in the instruction of engineers, physicists, mathematicians, and statisticians . . . the language they use is called BASIC. It is a basic idea of the system to have a language that's simple and that can be learned in a short time by the student and the instructors . . . . This system has two sizeable GE computers . . . and about thirty stations which are standard teletypes. (This is a truly time–shared system . . .) The student in statistics who goes on the machine has available a large library of routines which he can call up for the more standard statistical calculations . . . . A student can also do a lot of sampling experiments on a variety of distributions to get a feel for these distributions that he might not get from their analytic representations. He can vary the parameters of the distributions very easily and ask the computer to spew out thousands of samples in thirty seconds and watch the array of sampling behavior . . . .

The UCLA System

And now I'll describe a course that I'm involved with that's supposed to be operating one year from now at UCLA. We will use a time–shared system, the one in use at System Development Corporation, to do work from remote stations at UCLA. We will have at least two student stations: one in the psychology department and one in the school of education; and possibly a third in the school of public health . . . an aim of this course will be to see if we can drive home concepts in statistics through the use of the computer by essentially substituting sampling experiments for the difficult mathematics, usually probability, needed to demonstrate the concepts . . . . The theory is that with this computer on–line interacting with the student we can provide him with lots and lots of experience or a simulated experience that may be closer to his work experience . . . .

We hope to break the course down into essentially three pieces; one would be an expository piece which may have some programmed instruction in dialogue form, but will certainly have some artfully chosen examples designed to dispel the mystery of what a statistical test is for someone who doesn't have mathematical training, what a confidence interval is, what a measure of relationship between two variables may be . . . .

We will have a laboratory phase where the student will be presented with lots and lots of problems . . . . He will get a graded sequence of exercises where the data for these exercises will be randomly generated . . . . Then there will be a vast array, perhaps sixty, statistical subroutines that the student can call up to use on these problems . . . .

And the most daring piece . . . is that we have said that we will produce some question and answer capability in this system . . . with a limited fund of information to search, it may be feasible . . . to collect a series of queries as we observe them in the students and to build enough information into this base so that when the student queries the computer, it will reply appropriately. It will permit him to ask questions tied to some of the problems in the expository phase . . . .

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[3] The BASIC language used in the Dartmouth system is characterized briefly in Appendix G. An example of an instructional program in physics for the system is described in Appendix E.

appendix e

Computational Mode Physics Programs

This appendix describes briefly some of the ways in which the computer as a high-speed calculating machine has been introduced into undergraduate physics curricula at various colleges and universities. The examples that follow serve one or more of the following functions: to illustrate fundamental physical principles, to give students some experience with simple techniques of numerical analysis, and to introduce students to the computer and to the basic computational mode programming languages. It should be stressed that these are programs which can be used at the present time in almost any college which has a digital computer. Although the convenience of adaptation will depend on the nature of the available equipment, most of the programs described below can be converted readily from the particular computer for which they were developed to any other digital computer of similar or greater capacity. These programs provide evidence that, at least in the areas described below, the computer can be, and indeed has been, used effectively in physics instruction.

Numerical Integration of Equations of Motion

This example, devised by Alfred M. Bork for an introductory course for nonscience students at Reed College, is based on the approach to the equations of motion given in Chapter 9 of the *Feynman Lectures on Physics*, Vol. I. In his illustration, Feynman follows the Euler method of replacing derivatives by average values, but refines it by first calculating an initial half step in the velocity. He illustrates the method and the meaning of the equations of motion for two forces, the linear force of the harmonic oscillator problem and the gravitational force. In the text the method of numerical integration is discussed, and the results compared with the analytic answer.

After a study of the examples in Feynman, the students are asked to try to apply the techniques to other forces. While most of them could formulate the problems correctly, carrying out the calculations with Δt small enough for accurate results involves much hand labor, and leads naturally to a demand for computational assistance.

Before the students are introduced to the computer, they write for the harmonic oscillator problem a set of instructions intended for a "secretary"–someone who knows nothing about mechanics but knows how to perform simple numerical operations and how to follow directions. (A set of instructions of this kind, carefully done, will almost be a computer algorithm.)

Then, with no previous study of FORTRAN, the students are *given* FORTRAN programs for the harmonic oscillator and the gravitational problems, both of which follow Feynman's method of calculation. These programs are discussed line by line, with explanations of what is happening at each step. Introducing students to FORTRAN in this way rather than through an instruction manual is similar to learning a language through conversation.

With the FORTRAN program for the harmonic oscillator running on an IBM 1620 computer, the students can experiment with the parameters of the numrical integration. Feynman uses only one value of Δt, so that it is not clear how the solution depends on the size of the time interval. The students are allowed to decide as a group what steps Δt should run, and to enter this program into the computer. The exact solution is printed out along with the result of their numerical integration, showing what accuracy is obtained for various Δt's.

The students' first unassisted program involves solving the harmonic oscillator problem using the simple Euler method *without* putting the velocities on the half step, which requires only a slight modification of the existing program. The result surprises even experienced physicists if they have had little previous experience in numerical analysis. Feynman says that assigning the velocities to the middle of Δt is an improvement, but now the students see directly just how much it does improve the results.

With the gravitational force problem the students already have some idea of what step gives decent answers, so the emphasis is on initial conditions. Feynman works only one case, an elliptical orbit; he does not suggest, and it is not suggested in class, that open orbits are possible. The problem is presented as one of determining how variation of initial conditions affects the motion of the planet or satellite. The students devise a plan for studying this systematically.

The program allows them to enter new initial conditions from the typewriter whenever they wish. Most groups decide that they will keep the position fixed and vary the velocity. (It must be explained to them that wild behavior occurs if the particle is allowed to get too close to the sun; that slight errors in the distance will lead to large errors in the calculation for a $1/r^2$ force at small distances.) Many students decide to keep the direction of the velocity fixed and alter only its magnitude. The first time students "fire" the satellite at a velocity sufficient to give a hyperbolic orbit, they are surprised. As they watch the computer print-out, someone gradually begins to realize the satellite might not come back!

The next problem is locating the boundary between closed orbits and open orbits. Since the program calculates the total energy at an early stage, the relation between open and closed orbits and the total energy may emerge as an empirical generalization.

The damped harmonic oscillator is the next assignment. The FORTRAN program is not too different from the previous program for the oscillator.[1] The class produces the program, runs it, and has the responsibility of finding the errors and correcting them. (A common error is to leave out a multiplication sign between the damping constant and the velocity.)

Harmonic Oscillator in Quantum Mechanics

The following example has been used by Alfred M. Bork with an IBM 1620 computer in sophomore classes at Reed College and the University of Alaska. Its purpose is to allow a discussion of the eigenvalue problem in quantum mechanics before the student is able to solve the Schrödinger equation by analytic methods.

Two FORTRAN programs were written for the harmonic oscillator problem, the first using the Euler method of integration and the second, described here, a more sophisticated method. The time-independent Schrödinger equation was integrated for various values of the energy W specified by an initial data card. Each integration began at the origin, and for each value of W two different sets of initial conditions were used; first $\psi = 1$ and $d\psi/dx = 0$, and second $\psi = 0$, $d\psi/dx = 1$. No attempt was made to normalize the solution. The calculation started with a Taylor series expansion at the origin, including terms in $(\Delta x)^4$. The integration method was that of Numerov,[2] particularly suitable for linear second-order equations with no first derivative term.

The calculation was stopped in one of two ways, depending on whether or not the solution was a possible eigenfunction. If the solution exceeded in absolute value a number specified on the data card (1.5 was satisfactory), the calculation proceeded to the next value of W. Otherwise each case continued until x was 1.5 greater than the classical turning point for that particular value of the energy, and a message was typed indicating that the function was a possible eigenfunction. This did not prove that the square of the function was integrable, but no such "proof" is forthcoming with approximative methods. Indeed, it is almost certain that any solution carried to larger and larger values of x will eventually diverge, for the method is approximate, while an eigenvalue is a sharp, discrete occurrence.

Output was on punched cards, with spacing of the independent variable in intervals of 0.1. Punching for noneigenfunctions was controlled by a sense switch. A program in the 1620 General Program Library (9.7.003, in GOTRAN) was modified for plotting the curves on Ditto masters. This program scaled the data. From a pedagogical point of view an on-line plotter, had it been available, would have offered distinct advantages.

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[1] By this time we have discussed how to write FORMAT statements.

[2] D. R. Hartree, *Numerical Analysis* (Oxford University Press, New York, 1952), Sec. 7.22.

Lattice Vibration Spectrum

This is a problem or series of problems which has been used by Arthur Luehrman in the junior– or senior–year course in solid state physics at Dartmouth College.[3] Typically at present, a one–dimensional arrangement of springs and masses is worked out in detail by hand, and the frequency *f* of each normal mode is found. Then the one–dimensional reciprocal space (**k**–space) is introduced, together with the Brillouin Zone. This gives a geometrical significance to the normal modes, and *f* is thought of as a function of a **k**–space argument. One would like to be able to pursue this same regime for a model more realistic than the elastic line, where the effects of higher dimensionality are felt.

The first step in this direction is a homework problem centered on a two–dimensional square array of masses and nearest neighbor springs. The analytic form of *f*(**k**) can be found easily, but its contents are brought out by having the student plot a family of some twenty curves of constant *f* on a graph whose axes are $\mathbf{k}_x$ and $\mathbf{k}_y$. A computer is recommended for this, but by no means necessary. A glance at the plots suggests simple behavior of the function *f*(**k**) at certain points in **k**–space. The students are then asked to investigate analytic expansions of *f*(**k**) near these points, and so to validate the hunches suggested by the numerical results.

Next the lattice spectrum or density of states D(*f*)—i.e., number of modes lying between *f* and $f + df$—is required. In the one–dimensional problem this is nothing more than a trivial change of variable from **k** to *f*. But in n dimensions it involves the integration over $n - 1$ dimensions in a very complicated manifold. Therefore it is never attempted in a conventional course, even though the student is told that it is one of the most important theoretical aspects of a solid.

However, the problem is quite simple to solve on a computer with an eight–line program (in the BASIC language). The student is told to solve the problem by evaluating *f*(**k**) at 10,000 or so points in **k**–space, either randomly chosen or selected via a regular mesh. The range of *f* is divided into some fifty intervals and a histogram approximating D(*f*) is built up. The student typically solves this problem in about an hour of his time and two or three minutes of (medium–size) computer time.

The result once more leads him back to an analytic exploration of the behavior he sees. For example, a strong peak shows up in his histogram and he notices that the value of the frequency there lies, in his earlier plot, on a contour which runs through a saddle–point of *f*(**k**). He is asked to explore this region analytically and to prove that in fact the peak is due to a logarithmic singularity in the lattice spectrum.

In summary, this exercise–in–depth brings a realistic problem within grasp of the student and encourages him, by the visible presence of unexpected details, to engage in a *far closer analytic examination* than would occur without the numerical and graphical results.

Use of Computers in Lecture Demonstration

The computer has been used in the following ways as an aide to classroom demonstration at MIT (Malcolm W. Strandberg).

1. *Band Theory for a One-Dimensional Solid*

In discussing the band theory of solids, a program with the PDP–1 computer allows an investigation of the energy bands and wave functions in a one–dimensional solid with such various lattice potentials as delta function, parabolic (harmonic oscillator), sine wave, square well, and truncated Coulomb potentials. The cathode ray tube output is used to present the wave function visually. The limitation of CRT size is overcome by slowly drifting the section of the wave function viewed along the lattice for as many lattice displacements as desired. The computer seeks the edges of bands using the periodicity and symmetry of the wave functions at the band edges. The program has its greatest value in indicating to the student the sensitivity, or insensitivity, of the essential features of band theory to changes in details of the model (i.e., strength of the delta function or the precise shape of the lattice potential).

The fact that the wave functions are readily available is essential, since one can immediately investigate the nature of the wave function in the allowed and forbidden bands (its divergence in the forbidden bands being the physical reason for the forbiddenness). It also provides a convenient method of explaining the existence of localized modes or surface states. More importantly, one can respond immediately to student questions; e.g., what will happen to the periodicity as the energy is increased above its value at the bottom of an allowed band? The wave functions are readily available, and the periodicity can be followed with energy change to investigate the energy dependence of the wave function. By such response, one can satisfy both the analytically-oriented student and the student who best understands qualitative physical discussions.

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[3] The Dartmouth remote terminal computer system is described briefly in Appendix D, and the BASIC programming language which it uses is characterized in Appendix G.

The validity of the vicarious experience in band calculations afforded by the computer is reflected in the level of student discussion in following periods. For example, students become interested in the dependence of the actual band structure on the potential; could, in fact, the potential be inferred from the band structure? Having gone this far with a one-dimensional solid, it seems to be easier for the student to accept some of the simple ideas connected with more realistic three-dimensional models.

2. *Pendulum*

A second example of the use of a computer in lectures is intended for a freshman physics course, and concerns the motion of a pendulum. Here the velocity, acceleration, and displacement of the pendulum are calculated and displayed on the computer CRT as a function of time. The initial displacement can be varied and the breakdown of the usual linear approximation can be studied by noting the effect of the initial displacement on the time dependence and acceleration, and on the period. The computer also constructs a table of periods for various initial displacements. These displacements are plotted to show the student where linear approximation breaks down, the direction of change of the period, and its rate of increase with initial displacement. This quantitative investigation of the real motion of the pendulum helps the student to gain an intuitive feeling for the limits of validity of the linear approximation, the conditions under which the approximation breaks down, and the rate at which error develops; useful and profitable points to make economically with the computer, but too time-consuming for hand calculation.

Variational Principles and Classical Mechanics

This is an example of a program designed to give the student (sophomore- or junior-level science major) a feel for Hamilton's principle, and more generally for any variational principle. It has not yet been implemented, but would require a computer or remote terminal with typewriter, cathode ray tube display, and light pen, and would proceed as follows:

1. The student types his name and the program name.
2. The cathode ray tube or typewriter asks him (via printed message) to specify the Lagrangian or the potential function.
3. The student replies and is asked to type in the function.
4. Axes with full labels appear on the screen. They remain during the rest of the program.
5. The student is asked to mark the end-points of the motion with his light pen, and two points (labeled "initial" and "final") appear and stay on the screen.
6. The student draws *any* curve between the points, and the value of the action (with label) for the given Lagrangian and path appears on the cathode ray tube face.
7. The student draws another possible path *which appears with* the first path. The action for this path also appears on the scope. The path with the *least* action of the two *stays* on the screen, with the value of its action, and the other path fades. The action is labeled "best path drawn."
8. The student continues in this fashion, trying to make the action smaller and smaller.
9. When he decides that he has tried long enough, he asks for the physical path and its associated action. This is drawn in a way that is distinguishable from the "best" path of the student. If desired, the student can terminate the program here.
10. The student can ask for his best path to be erased.
11. He can then draw paths in the neighborhood of the physical path and see directly that any deviation increases the action.
12. Termination.

appendix f

University of California, Santa Barbara, Computer System

Over the past several years a problem-oriented programming system and computer terminal have been developed, largely at TRW Systems in Canoga Park. Although the system was devised with the solution of research-type problems in mind, it has recently been used successfully for instructional purposes at the University of California, Santa Barbara campus. Currently we have a classroom at Santa Barbara equipped with sixteen of these computer terminals. In addition, there is one terminal at UCLA tied into the Santa Barbara computer by telephone line, and there will soon be two more stations at Harvard tied into it.

The system was designed around four central characteristics:

1. *Direct control.* The user has immediate command of the computer, and can, from a keyboard, initiate a number of basic subroutines built into the system, as well as additional ones which he creates by console programming.
2. *Direct Feedback.* The results of any calculation are immediately available to the user, displayed on a cathode ray tube (CRT) either as numbers or in graphical form.
3. *Functional Orientation.* The computer is programmed to act as a "function computer"; that is, one which deals with functions (in the mathematical sense) as entities, rather than individual numbers, and whose repertory of instructions includes the basic operations of classical analysis (such as exponentiation, trig functions, etc.) rather than only those of arithmetic. The simplest kind of function on which the machine would operate, for instance, would be a real function X. To the machine, this function would be a series of values of the function

   $$X = (x_1, x_2, x_3, \text{----}\ x_N),$$

   or a real vector. At present, N is limited to values of 124 or less at Santa Barbara. Complex functions are represented as two vector arrays, and so forth. In the above case, the X-key on the console represents not just a single number, but the whole array of numbers which describe the function.
4. *Console Programming.* By simple keyboard operations, the user can, at the console, combine any of the basic subroutines into new ones specialized to his needs. These new subroutines can then be assigned to available keys stored in the disk memory of the computer, and later called upon by merely pressing the assigned key, in the same way that the basic, built-in subroutines are called. Such special subroutines can, in turn, be included in more complicated subroutines, thus providing all of the programming aspects required in computing, but without the time lags typically associated with conventional procedures.

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[1] The following is a written version of an invited talk presented to the Conference by Glen J. Culler, Director of the University of California, Santa Barbara Computer Center, and a Professor of Mathematics at UCSB.

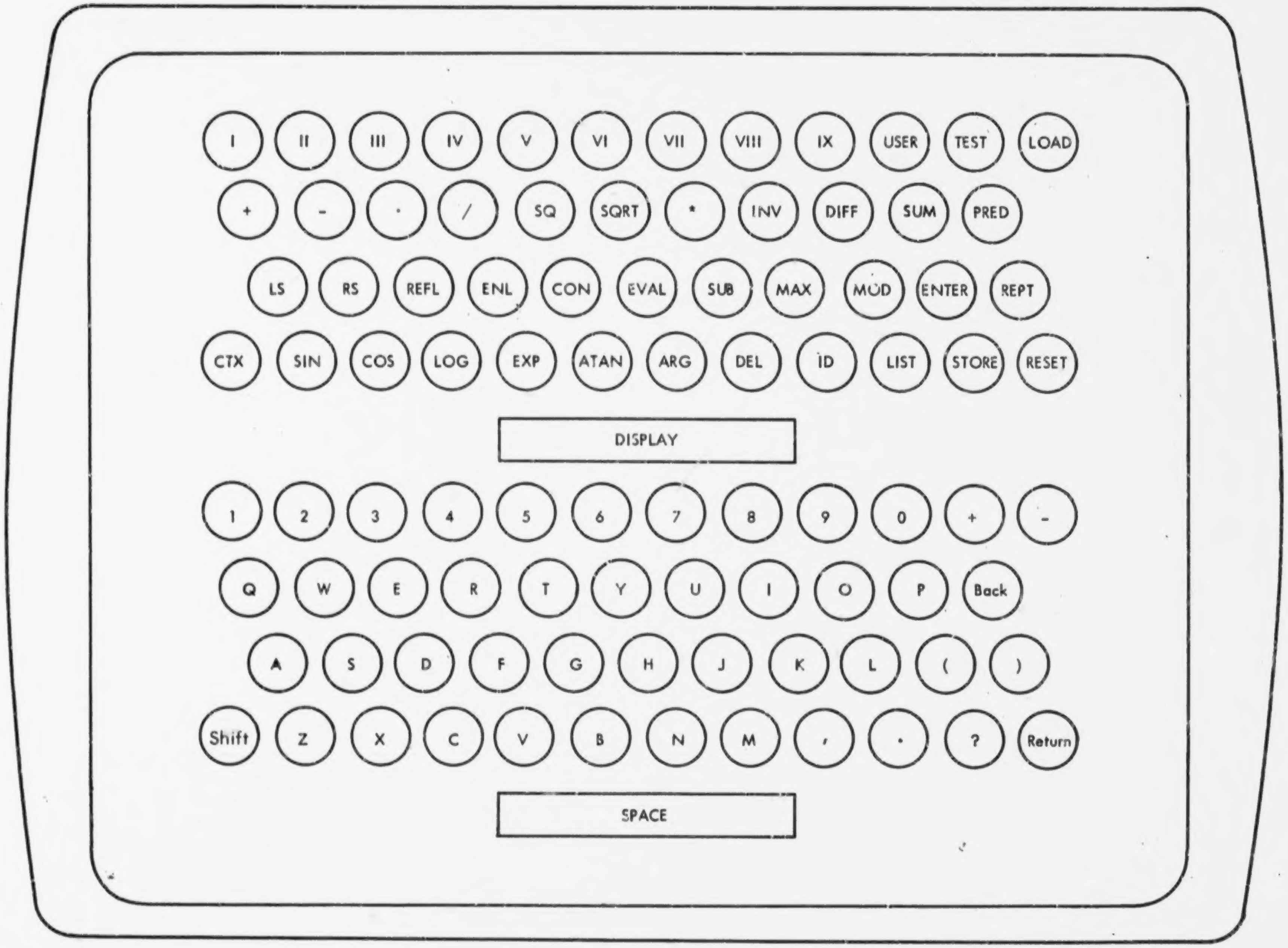
I II III IV V VI VII VIII IX USER TEST LOAD
+ - · / SQ SQRT * INV DIFF SUM PRED
LS RS REFL ENL CON EVAL SUB MAX MOD ENTER REPT
CTX SIN COS LOG EXP ATAN ARG DEL ID LIST STORE RESET
DISPLAY
1 2 3 4 5 6 7 8 9 0 + -
Q W E R T Y U I O P Back
A S D F G H J K L ( )
Shift Z X C V B N M , . ? Return
SPACE

Figure 1

The double keyboard of the BBN Teleputer console. The upper keyboard is for operators, the lower for operands. In addition to the labels shown, the keys are color coded according to their functional role in the system.

The central computer used for the system at Santa Barbara happens to be a time-sharing Ramo-Wooldridge RW400, although nothing in the programming system is specific to this kind of computer. One of the consoles used at Santa Barbara is shown in Fig. 1.[2] At present, typewriter keyboards and storage oscilloscopes provide the most economical basic input/output devices for on-line computing. The storage oscilloscope is a standard Tektronix model, and the system is programmed to write alphanumeric characters on its face and to construct graphical displays. Alphanumeric characters are written at a rate of about 25/sec and displayed about twenty-five to a line across the five-inch CRT face. As an input device, the double keyboard shown in Fig. 2 is mounted on the console. The keys operate microswitches, and are designed to do so quietly. This is a necessary feature of consoles to be used in a classroom. As you can see, the upper keyboard is associated with operators, and the lower one with operands. Each operation is carried out by pushing a single key of the upper keyboard.

Being function-oriented, there are several levels on which the system can operate. Levels are changed by a small subset of operator keys designated as "level indicators," analogous to the case shift on a typewriter. At present, in the nine basic levels of the system, the operators operate on:

I. single numbers (or single components of a vector);
II. real functions or real vectors;
III. complex functions or complex vectors;
IV. (not implemented at present);
V. (not implemented at present);
VI. real matrices (under development);
VII. complex matrices (under development);
VIII. statistical programs and functions (under development); and
IX. editing programs with alphanumeric capabilities (under development).

The operation EXPON X would, for example, produce on level I one value exp (X); on level II the exponential of each of the N components of the vector X; and on level III the real and imaginary parts of the exponential of each of the N components of X. In other words, on levels I, II, and III, there are respectively 1, N, and 2N results of each operation, be it a basic keyboard operation or one which has been programmed and stored. Because the system is function-oriented, operations on level I are very inefficient; you spend as much time locating the operand as you do performing the operation.

Returning to the lower or operand keyboard, each key corresponds to a storage location in some mass storage device (a magnetic disk in the Santa Barbara computer). Data transfers between this and the computer are effected with the operator keys LOAD and STORE. For instance, pressing the two keys

LOAD A

(operator and operand, respectively) brings the data in storage location A—a number, vector, or some other kind of list, depending on the level—into the computer's magnetic core memory, while STORE A accomplishes the converse.

To facilitate the function of console programming and to increase the addressable storage capacity of the system, nine user levels are available on each key. For example, to store a program, under RS on user level V, one presses the four keys

STORE USER V RS

Additional programs could be stored under the RS-key on the other user levels, if desired.

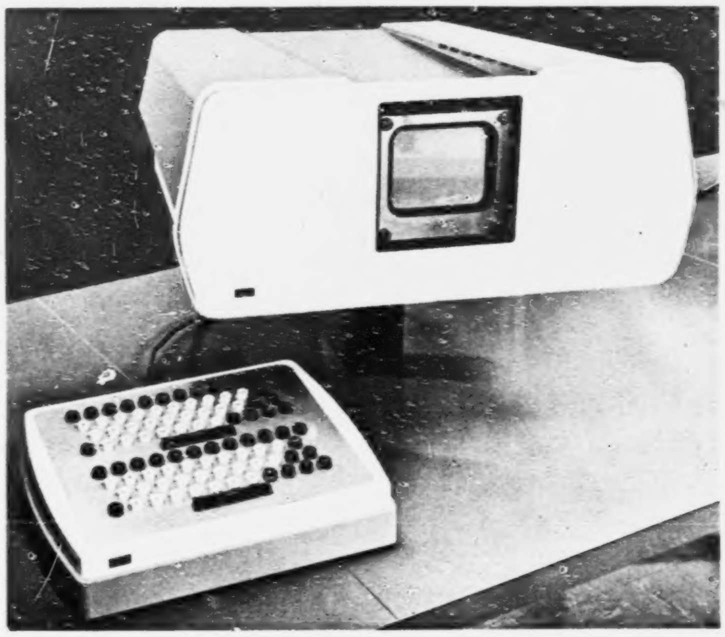

Figure 2

The Bolt Beranek and Newman Teleputer console, used in the Santa Barbara on-line computer system.

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[2] These consoles are now being manufactured commercially by Bolt Beranek and Newman. A more detailed description of the BBN Teleputer console appears in Appendix B.

A further, very detailed description of the programming system would be out of place here. For those who would like more specific information on how the system works, a detailed, annotated example of a rather simple program has been appended to this report. This particular example is one which might be suitable for use in a calculus course (or even a physics course studying velocity and acceleration): a program is written to perform a numerical differentiation, stored on the disk, then called out and used to calculate the derivative of a sine function for various values of the increment H.

Now, how do we use these terminals in teaching undergraduates at Santa Barbara? The sixteen console stations, located in the classroom as shown in Fig. 3, are presently used in three courses: a second-semester calculus course, a constructive methods (computing) course which I teach, and a biometrics course.

The student consoles are connected with the teacher's console in such a way that:

1. The teacher can display what he is doing on each of the student terminals.
2. The student terminals can operate independently, but the teacher can dial any one of them and monitor the student's work.
3. An individual student can switch his terminal to the teacher mode, and display his work to the rest of the class on their terminals.

For the calculus course, the consoles are used during the off-semester so that we don't have to work with 1,000 students. There are three lectures plus one section meeting per week for each student, with about thirty students per section. The sections are then split in two so as to fit into the computer terminal lab, and they alternate every other week there. In a sense, the

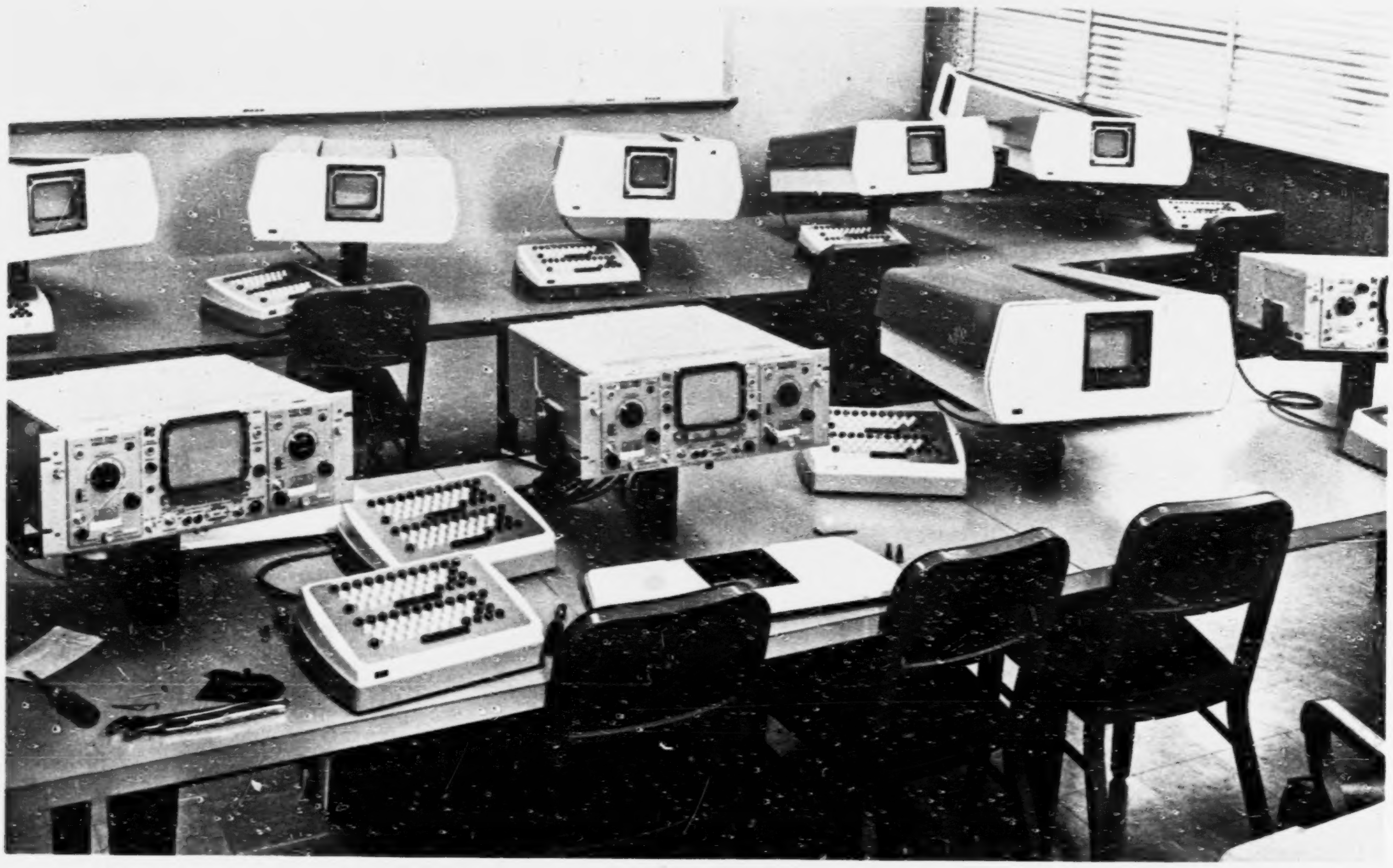

Figure 3

The computer terminal classroom at the University of California, Santa Barbara. The instructor's console is visible in the upper right hand corner of the room. Several of the consoles are shown with their display housings removed, illustrating that the display units are standard Tektronix Type 564 storage oscilloscopes, each with Type 2A60 vertical and horizontal plug-in amplifiers.

terminals are used as a very powerful blackboard. I've found that, sitting and talking to the class, I often think of something to illustrate; I program it quickly, show it, and go on to do something else just as I would do on the blackboard, but of course with a power the blackboard does not have. For instance, when the class is studying the concept of the derivative, the teacher may illustrate the definition by constructing, on the spot, the simple program appended to this report. He can use it on one example, and the individual students can try it on functions of their own choosing. Later on, when studying differentiation of complicated, perhaps transcendental functions, they can use the same program to either gain some intuition into what the derivative should look like, or to check their analytical result numerically. Or, instead of using the stored program created by the teacher, they could be asked to construct their own little numerical differentiation program. By such use of the terminals, one might achieve an organized laboratory treatment of calculus which may be orders of magnitude better than what we've been doing in our calculus sections.

For his Biometrics course at Santa Barbara, Jim Ross has incorporated a random number generator, and a SORT operation under the SQRT key (take the tail off of the Q and it becomes SORT). The SORT operation orders a list of numbers by magnitude. With these and other operations which he's programmed, he can use the computer to illustrate quickly and numerically many of the statistical ideas that his students really don't understand from a mathematical point of view.

In order to give the user the feeling that, when he punches the SINE key, the sine of a function is really computed, the turn-around or response time of the system should be of the order of 1/10 sec. At level II-type sophistication (i.e., lists of real numbers), using a computer with 5-microsecond multiply time, full core storage in order to get the flow up, and a good disk, the system could handle 125 people at consoles, leaving them all with the feeling they can do anything you want them to. But since half of them won't be doing anything, you should still have about 50 per cent of the computing time available for background calculations on the time-sharing system.

The on-line system of computer terminals we've developed was designed to act as an extension or augmentation of the reasoning power of the human operator, usable by him in the most natural way and under his continuous control. As such it has been of enormous use in research calculations, and its application to instruction is going to increase greatly the scope of things that we can do for students in quantitative math and science courses.

References

G. J. Culler and B. D. Fried, "The TRW Two-Station On-Line Scientific Computer: General Description." In *Computer Augmentation of Human Reasoning*, edited by Margo A. Sass and William D. Wilkinson (Washington, D. C.: Spartan Books, 1966).

W. J. Karplus, ed., *On-Line Computing in Time-Shared Man-Computer Systems* (New York: McGraw-Hill, fall 1965).
This book, based on lectures given under the auspices of the University of California extension service, contains a chapter by G. J. Culler which is in essence a user's manual for the BBN Teleputer, and a chapter by B. D. Fried on problem-solving techniques with such an on-line terminal.

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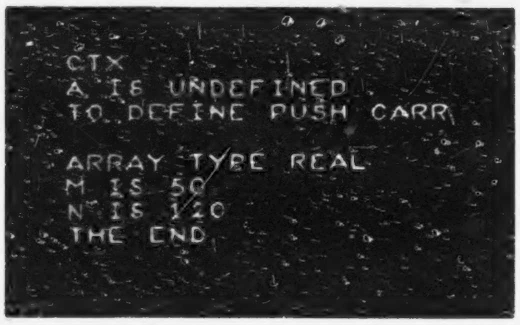
A SIMPLE PROGRAM FOR THE SANTA BARBARA ON-LINE COMPUTER SYSTEM

Keyboard Entries
(Each underlined symbol or group of symbols represents one key.)

Computer Displays

---

1. IX CTX A
   RETURN
   R
   5 0
   1 2 0



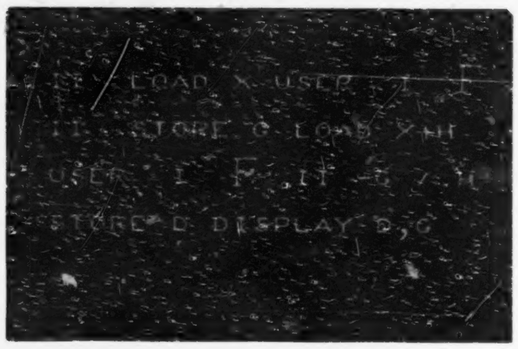
```
CTX
A IS UNDEFINED
TO DEFINE PUSH CARR

ARRAY TYPE REAL
M IS 50
N IS 120
THE END
```

EXPLANATION

A list of real function values, or a vector, occurs as a column in a two-dimensional array. In answer to the question "ARRAY TYPE" the nature of an array is specified as Real by depressing the key R. The size of real arrays is set at 50 columns (M) and 120 rows (N) in answer to appropriate questions displayed by the computer. This then defines any real function (column vector) as consisting of 120 numerical values.

To initiate the process of defining A, the user requests level IX (editing programs) and asks for the context comment stored under A (CTX A). Depressing the RETURN key (carriage return) in response to the request "PUSH CARR" brings forth the above question-and-answer sequence defining the nature and size of arrays.

2.
```
ERASE*
LIST II LOAD X USER I +
II STORE G LOAD X + H
USER I + II - G %. H
STORE D DISPLAY D , G
LIST STORE USER I DIFF
```



```
II LOAD X USER I F
II STORE G LOAD X+H
USER I F II - G ÷ H
STORE D DISPLAY D,G
```

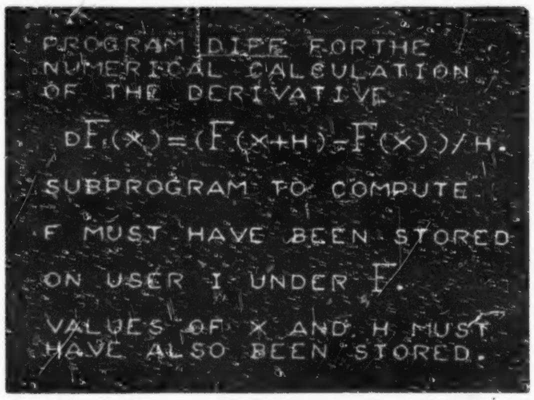
EXPLANATION

The CRT screen is cleared (ERASE), and a numerical differentiation program is written (the keys between LIST . . . LIST) on level II (real functions) to compute the derivative of a function F of an independent variable X. Reading the program itself from left to right, a set of values of X is loaded into computer memory, and the function F(X) is computed and stored in location G on the disk or drum. F is any arbitrary function which has been programmed (see step 4) and stored under the operation key + on user level I. In addition to this function, the display for the F which appears on the CRT has been previously programmed and stored on user level I under the + key. Following the shift to user level I, the computer is shifted back to level II (real functions) by depressing the II key on the operation keyboard. (It may or may not have been left in level II by the program F.) Similarly F (X+H) is computed, G subtracted from it, the difference divided by H, and the quotient stored under D. Then G=F(X) and D(X) are displayed on the CRT. STORE USER I DIFF stores this program under the key DIFF on user level I.

---

* Some of the terminals used in the Santa Barbara system do not have ERASE keys. On such terminals, the ID key performs the erase function when the user is typing or listing information, and the SPACE bar performs that function when calculations are being carried out.

```
3.  ERASE
    LIST P R O G R A M  D I F F  F O R  T H E
    N U M E R I C A L  C A L C U L A T I O N
    O F  T H E  D E R I V A T I V E
    D  SHIFT  2  F  SHIFT  1  ( X ) = (
    SHIFT  2  F  SHIFT  1  ( X + H ) -
    SHIFT  2  F  SHIFT  1  ( X ) ) / H .
    S U B P R O G R A M  T O  C O M P U T E
    F  M U S T  H A V E  B E E N  S T O R E D
    O N  U S E R  I  U N D E R
    SHIFT 2  F  SHIFT  1 .
    V A L U E S  O F  X  A N D  H  M U S T
    H A V E  A L S O  B E E N  S T O R E D .
    LIST STORE USER I CTX DIFF
```



```
PROGRAM DIFF FORTHE
NUMERICAL CALCULATION
OF THE DERIVATIVE

 DF(X)=(F(X+H)-F(X))/H.

SUBPROGRAM TO COMPUTE

F MUST HAVE BEEN STORED

ON USER I UNDER F.

VALUES OF X AND H MUST
HAVE ALSO BEEN STORED.
```

EXPLANATION

The material between LIST . . . LIST is typed in as the text of a comment and stored under the key DIFF on user level I as a context (CTX) comment which explains what the program does. The comment can be displayed on the CRT before the program runs, as in step 6 below. Note that to display the fancy symbol F one must shift 'case in typing; i.e., shift from symbol table level 1 to 2, then back again. This has been done in lines 4 and 7 of the above display, but not for the F in line 6. The symbol F has previously been formed and stored by a procedure which we do not discuss here. Its display is stored under both the operation key + on user level I and the operand key F on symbol table level 2.

```
4.  ERASE
    LIST II SQ LIST STORE USER I +
```

The symbols between LIST . . . LIST appear on the CRT.

EXPLANATION

A subprogram to calculate $F(X)=X^2$ for real functions is stored under the key + on user level I.

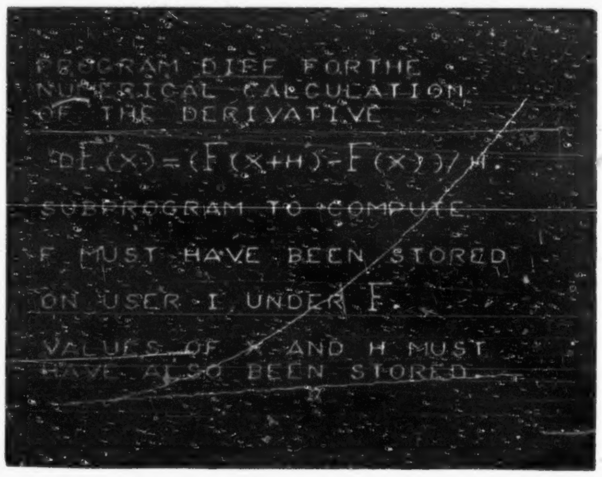
5. II ID · 5 + 5 STORE X LOAD
0 . 1 STORE H

Since the computer is not placed in the LIST mode, this series of keys results in no further CRT display.

EXPLANATION

This series of operations loads 120 numbers, equally spaced in the interval -1 to +1, into computer memory (this is the built-in ID function). These are converted into 120 numbers equally spaced between zero and 10, and stored under operand key X (the independent variable). H is set equal to C.1.

6. ERASE
USER I CTX DIFF
(This causes the comment to be displayed.)
USER I DIFF
(This causes the program itself to run, resulting in the two curves shown superimposed on the comment.)



PROGRAM DIFF FORTHE
NUMERICAL CALCULATION
OF THE DERIVATIVE
DF(X)=(F(X+H)-F(X))/H.
SUBPROGRAM TO COMPUTE
F MUST HAVE BEEN STORED
ON USER I UNDER F.
VALUES OF X AND H MUST
HAVE ALSO BEEN STORED.

EXPLANATION

The CRT is erased, the context comment displayed, and the program run, giving a graphic display of $F(X) = X^2$ and DIFF $F(X) = 2X$ for $0 \leq X \leq 10$.

7.	ERASE LIST II LOAD Y SIN STORE Z LOAD Y COS + Z LIST STORE USER I +	The CRT is erased and the information entered in the LIST mode is displayed.

EXPLANATION

A new function for F (X) = sin X + cos X is programmed and stored under the operation key + on user level I.

8.	LIST II LOAD X USER I + STORE G LOAD X + H USER I + - G % H STORE D LOAD H % 2 STORE H DISPLAY D . G USER I LIST STORE USER I DIFF	The information entered in the LIST mode (between LIST . . . LIST) is displayed on the CRT along with that remaining from step 7. (When the + key is depressed, the symbol F is displayed.)

EXPLANATION

The main program DIFF of step 2 has been rewritten to iterate for decreasing values of H. It has been caused to terminate on user level I so that it can be repeated automatically by merely depressing the DIFF key, in the manner demonstrated by step 10.

9. ERASE
II ID · 6 . 2 8 STORE X SUB X LOAD
0 STORE Y DISPLAY Y III REFLECT
STORE Y DISPLAY Y II

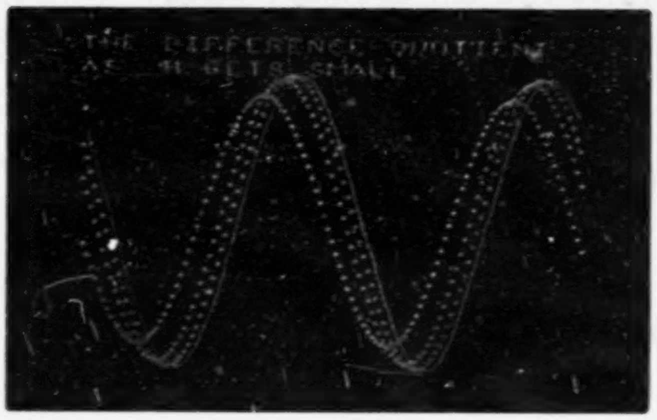
The previous display is erased, and X and Y coordinate axes appear centered on the CRT.

EXPLANATION

First the 120 values of the independent variable are set to range between $-2\pi \leq X \leq 2\pi$. The keys SUB X put the list X into the X-coordinates (abscissa) of the graphic display. The next six keys cause the function Y = 0 (the X-axis) to be displayed. Transfering to level III (Complex functions), the REFLECT operation interchanges the X and Y (real and imaginary) axes, so that STORE X DISPLAY Y plots the Y-axis of the coordinate system. Finally, the computer is transferred back to level II operands.

10. LOAD 1 STORE H USER I REPT
DIFF 4 RETURN

H = 1/8
H = 1/4
H = 1/2
H = 1



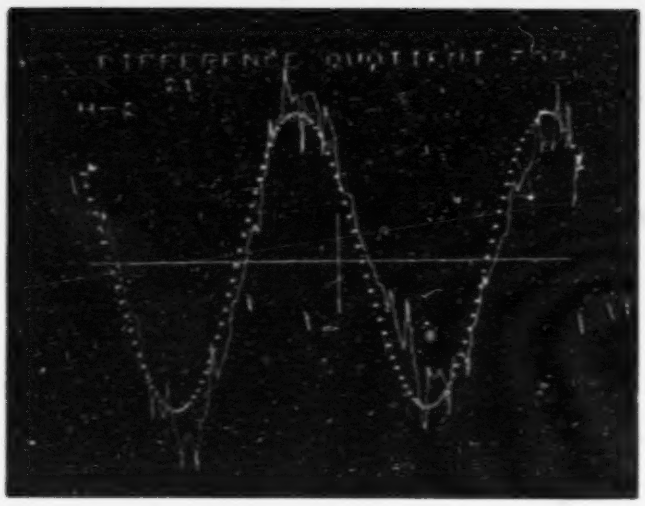
EXPLANATION

The initial value of H is set equal to 1 and the program is repeated (REPT) four times, for values of H = 1, 0.5, 0.25, and 0.125. The RETURN key is depressed to inform the computer that the user has finished typing in the number of repetitions desired. Otherwise the computer would not know whether further digits were to follow the 4: for example, 42 or 497 repetitions. The photograph shows the resulting CRT display, with the following variations:

a) The coordinate axes resulting from step 9 are not shown.
b) The text at the top should not appear (this was added to the photograph for identification.)
c) All four curves should be continuous rather than dotted, as three of them are. The dotting was programmed specially to distinguish the curves.

(It is interesting to note that the principal error caused by choosing a large increment H is in the phase and amplitude of the resulting derivative, not in its smoothness. This result was at first mildly surprising to the person who actually ran the program, and illustrates the type of learning which can occur at such a computer console.)

11.



EXPLANATION

To illustrate the effect of rounding off errors for very small H, the derivative of sin X + cos X was calculated with $H = 2^{-21} \simeq 5 \times 10^{-7}$ (continuous, jagged curve). It is compared with the true derivative cos X - sin X (dotted curve). The coordinate axes are also shown here.

appendix g

Computational Mode Computer Languages

This appendix provides brief, informal commentary on some of the more commonly used computer languages for programming numerical computations.[1]

FORTRAN

FORTRAN is by far the most commonly used computer language for computational mode programs at present. It was designed by IBM in 1957 for the IBM 704, but is now available on almost every computer in the world. It is an algebraic language which describes calculations using expressions similar to those used in algebra. As with all computer languages, FORTRAN has many different "dialects," the three most widely-used being FORTRAN, FORTRAN II, and FORTRAN IV. Although there is no consistency in the use of these terms, FORTRAN II usually includes subroutines in the language, and FORTRAN IV usually includes the use of logical "IF" statements and complex variables.

ALGOL

ALGOL is a second generation algebraic language, succeeding FORTRAN and so having a somewhat more logical structure. ALGOL is not nearly as widely used in this country as it is in Europe. There are, however, many American machines with ALGOL compilers, although these compilers often omit some of the more esoteric features of the language.

JOSS

JOSS is an algebraic language which was developed by the RAND Corporation for use at time-sharing, typewriter-like terminals. It can be used either to program or to make the terminals operate as electronic desk calculators. Because it is intended for terminal use, it is designed to provide rapid feedback of grammatical errors made by the programmer. Variations of JOSS, under slightly different names, are now available at the University of California at Irvine (JOSSI) and at the University of California at Berkeley (CAL, not to be confused with Computer-Assisted Learning). A version called TELCOMP is available for use in the Boston area through Bolt Beranek and Newman.

BASIC

BASIC is an algebraic terminal language, similar in some ways to JOSS, which was designed at Dartmouth College for use on their time-shared computer system. It is also used at General Electric as a time-sharing language, and is available to other colleges through the use of centralized GE machines.

QUIKTRAN

QUIKTRAN is a terminal-oriented version of FORTRAN developed by IBM and available from them at terminals in certain large cities. Unlike JOSS and BASIC, it uses the full complexity of FORTRAN.

---

[1] Descriptions of existing programming languages for CAL in the linguistic mode are contained in Appendix A.

PL/1

PL/1 is a new language announced by IBM for implementation on some versions of their System 360 computer series. As of this writing, no experience is available with PL/1 compilers. The language combines the features of both an alegbraic language and a symbol– or list–processing language.[2] As an algebraic language it could be called a "third generation" language, succeeding FORTRAN and ALGOL. Because it combines algebraic and list–processing facilities, it allows complex programs which use both linguistic and computational modes.

---

[2] A list–processing language is specifically designed for the efficient processing of verbal information. For example, the COURSEWRITER and MENTOR systems described in Appendix A are essentially list–processing languages, as opposed to the computation–oriented languages described here.

appendix h

Glossary

This glossary contains definitions or explanations of many of the more frequently used and less familiar terms employed by computer specialists. Although an effort has been made to explain unfamiliar terms when they appear in the body and in the other appendices of this Report, or to avoid using them altogether, we have not been entirely successful in doing so. Therefore the glossary will be of some use in reading the rest of the Report. In addition, the publications of computer component manufacturers and computer experts are sometimes distinguished by a proliferation of somewhat obscure technical terminology. It is hoped that this glossary will also aid the reader in referring to and understanding other technical literature on computer systems in general, and CAL systems in particular.

Access time: Time required to obtain information from storage (read–time), or to put information away in storage (write–time).

Algorithm: "A rule of procedure for solving a recurrent mathematical problem." (Quoted from *Webster's Third New International Dictionary*.)

Analog computer: A device which uses voltages, forces, fluid volume, or other continuously variable physical quantities to represent numbers in calculations.

ASCII: American Standard Code for Information Interchange. This is the character code established as standard by the American Standards Association, and consisting of eight information bits plus one start and two stop bits per character, a total of 11 bits/character.

Bandwidth: The range of frequencies which can be transmitted over a communications channel (telephone line, radio channel, etc.). The bandwidth determines the amount and quality of information which can be transmitted through the channel per second (bps). This is equivalent to cycles per second (cps) or Hertz (Hz), with the usual multiples, Kilo– and Mega–.

Batch processing: A method of processing in which a number of similar input items or programs are accumulated and processed together.

Binary computer: A device using on–off switches (electromechanical relays, bi–stable circuits [vacuum tube or transistor], magnetic rings, etc.) to represent numbers in the binary system for calculations.

Bit: Contraction of term "binary digit."

Broadband: Of large bandwidth; at least bandwidth greater than that of ordinary unconditioned dialable telephone circuits, which is about 2,000 Hz or bits/sec.

Broadband Exchange Service (BXS): A data communications exchange switching service offered by the Western Union Telegraph Company. The service provides full duplex facilities at bandwidths up to 4 KHz (data rates up to about 2,400 bits/sec), with bandwidths up to 48 KHz a possibility in the near future. The user can dial the particular bandwidth he wants as well as the party he wishes to call, and can transmit and receive voice communications as well as data.

Buffer: A storage device used to compensate for a difference in rate of flow of data or time of occurrence of events when transmitting data from one device to another. The storage unit is often a magnetic core memory, and is referred to as buffer memory or buffer storage.

Byte: A group of bits (usually six to eight) forming a character.

CAI: Computer-assisted instruction; computer-aided instruction; computer-augmented instruction.

CAL: Computer-assisted learning.

CBI: Computer-based instruction.

Channel: A path for electrical signal transmission between two or more points. Also called a circuit, facility, line, link, or path.

Character: A digit, letter, or other symbol, usually requiring six to eight bits of storage. In data transmission, start and stop bits may be required for each character in addition to information bits. In the ASCII code, for instance, a total of 11 bits/character is required for transmission.

Compiler: A computer program for the translation of instructions expressed in a user language (for example, algebraic formulas) into machine language.

Core: The rapid access memory of a central processing unit; usually made up of many small rings (cores) of magnetic material, which may be in either of two states of magnetic polarization.

CPU: Central processing unit. The central section of a computer, including control, arithmetic, and memory units.

CRT: Cathode ray tube. In common use as a display device.

Cursor: A point or line of light displayed on the CRT, the position of which is under the control of either the user or the computer. The cursor is used to indicate the point at which the next display or editing operation is to occur.

Data Phone: A trade mark of the American Telephone and Telegraph Company to identify the data sets manufactured and supplied by the Bell System for use in transmission of data over the regular telephone network. It is also a service mark of the Bell System which identifies the transmission of data over the regular telephone network (Data Phone service).

Data set: A device which converts the digital pulses from a computer or an I/O terminal into audio frequency tone pulses for transmission over telephone lines or other communication channels. It is a telephone-like device, with provision for dialing another party and for voice communication with the other end of the line.

Disk: A stack of disks coated with magnetic material for the storage of information. Bits can be stored upon and read from it while it is revolving at high speeds.

Down-Time: Time when a machine is not operating correctly because of machine failure.

Drum: A cylinder coated with magnetic material for the storage of information. Bits can be stored upon and recovered from it while it is revolving at high speeds.

Duplex or full duplex: In communications, pertaining to simultaneous two-way, independent transmission in both directions. In contrast to half duplex (see below).

Facsimile (FAX): Transmission of photographs, maps, diagrams, etc., over communication channels. The image is scanned at the transmitter, reconstructed at the receiving station, and duplicated on some form of paper.

Foreign exchange service: A telephone exchange service in which the subscriber's telephone (or data station) is effectively located in a distant exchange area. An unlimited number of calls or data connections can then be made within the distant exchange area for a flat monthly charge. This service is limited to the usual telephone line data rates of less than 2,000 bits/sec.

Half-duplex: Pertaining to an alternate, one-way-at-a-time transmission facility (sometimes referred to as a "single"). In contrast to duplex or full duplex (see above).

Hardware: Computer components and equipment.

Interface: A shared boundary; for example, the boundary between two subsystems or two devices. An interface unit in a remote terminal computer system is a hardware component which "matches" devices to each other; for instance, a computer to several telephone lines from remote terminals, or a remote station to a telephone line. The unit may contain buffer memory, switching logic, and/or multiplexing facilities.

Interrupt: A hardware feature which allows the computer to stop working momentarily on one task, handle the interrupting task, and return to the first without losing information or interim results of processing.

INWATS: Similar to WATS (Wide Area Telephone Service–see below), but allows inward calls at a flat monthly rate.

I/O: Input/output of information to and from computers. Usually refers to devices such as electric typewriter, card reader and punch, paper tape reader and punch, etc.

K: Thousand; e.g., 32K words of memory means 32,000 words of computer memory.

LDX: Long Distance Xerography. A name used by the Xerox Corporation to identify its high-speed facsimile system. The system uses Xerox terminal equipment and a wide-band communication channel.

Light pen: A photo-sensitive device used for communication with a computer. When held against the face of a cathode ray tube, its position can be sensed. For instance, if the computer is suitably programmed, the position of the light pen can be interpreted in terms of a coordinate grid. The device can be used in this way to enter arbitrary graphical information, sketched by the operator on the CRT, into the computer memory in digital form.

Line switching: The technique of temporarily connecting two lines together, so that remote stations may interchange information directly.

Link: The same as a channel (see above).

Multiplexing: The division of a transmission facility into two or more channels, over each of which independent signals or data may be transmitted.

On-line: Connected directly to the central computer.

Polling: A centrally-controlled method of calling or interrogating a number of remote stations sequentially, to permit them to transmit information.

Process controller: A computer or computer subsystem designed to communicate with and control industrial, laboratory, or other processes. Such equipment may be useful in CAL because of the convenience of attaching teaching stations and instructional laboratory apparatus to them.

RAND tablet: A metal writing surface developed by the RAND Corporation for input of graphic information to a computer through the use of a special writing stylus.

Real-time: Performance of data processing during the actual time the physical process producing the data transpires, in order that results of the computation can be used to guide the physical process.

Refreshed CRT display: The more conventional type of CRT display, in which the image to be displayed is re-formed or "refreshed" at a rate of thirty to sixty times per second, so that it will persist without objectionable flicker. This requires scanning logic and buffer storage to drive the CRT. However, changes in the display can be made rapidly by merely changing the appropriate information in buffer storage, without destroying and re-forming the entire display. (See description of the storage oscilloscope below.)

Response time: The amount of time elapsed between generation of an inquiry at a data communications terminal and receipt of a response at that same terminal.

Software: Computer programs, as contrasted to computer components (hardware).

Station: One of the input or output points on a communications system.

Storage oscilloscope: A device in which displays are stored on the face of the CRT by electrostatic means. In order to change any piece of the stored information, the entire display must be erased and re-formed, making this device slower in response than refreshed CRT displays. At present, storage oscilloscopes seem to be less expensive than refreshed displays, but the situation may reverse in the near future.(See description of refreshed display above.)

Storage protect: A hardware feature which prohibits one user in a shared system from destroying the information stored in memory allocated to other users.

Student station: I/O equipment designed for student use, to permit the student to interact with the computer.

Teleprinter: A term referring to the equipment used in a printing telegraph system. A teletypewriter.

Tele-processing: A form of information handling in which a data processing system utilizes communication lines between stations and the processing unit (computer).

Teletypewriter exchange service: An automatic exchange switching service provided on a nationwide basis by the American Telephone and Telegraph Company (TWX) and the Western Union Telegraph Company (Telex).

TELPAK: A wide-band, leased line information transmission service offered by communications common carriers.

Terminal: A device attached directly to a computer through telephone lines, cables, or other communications links, and designed for user–computer interaction. Terminals may be located adjacent to the computer or at a remote location.

Tie line: A private communication channel of the type provided by communications common carriers (e.g., AT&T or Western Union) for linking two or more points.

Time sharing: A method of operation in which a computer facility is shared by several users for different purposes at (apparently) the same time. Although the computer actually services each user in sequence, its speed makes it appear that the users are all handled simultaneously.

Vector generation: The capability of drawing a line between two specified points on a terminal display device.

Voice grade channel: A communication channel suitable for transmission of speech, digital or analog data, or facsimile, generally with a frequency pass band of about 300 to 3,000 Hz. Voice grade channels can carry data at rates greater than about 2,000 bits/sec only if they are specially conditioned.

Wide Area Telephone Service (WATS): A service provided by telephone companies which, by the use of an access line, permits a customer to make an unlimited number of calls to telephones or data sets in a specific geographical zone for a flat monthly charge.

Word: A set of bits sufficient to express one computer instruction. Conventionally, a word consists of six characters, and therefore thirty-six to forty-eight information bits, or up to sixty-six bits for data transmission (see definitions of character and ASCII).

appendix i

List of Participants

E. N. Adams
Computer-Assisted Instruction
IBM Instructional Systems Development
Watson Research Center
Box 218
Yorktown Heights, New York 10598

Bruce Arden
Computer Center
The University of Michigan
1000 University Hall
Ann Arbor, Michigan 48104

Arnold B. Arons
Department of Physics
Amherst College
Amherst, Massachusetts 01002

Alfred M. Bork
Department of Physics
Reed College
Portland, Oregon 97202

Charles Branscomb
IBM Instructional Systems Development
Armonk, New York 10504

Lewis Bright
Westinghouse Corporation
3 Gateway Center
Pittsburgh, Pennsylvania 15230

Donald Brown
Center for Research on Learning and Teaching
The University of Michigan
1315 Hill Street
Ann Arbor, Michigan 48104

Harry N. Cantrell
General Electric Division of Phoenix
Computer Department
Deer Valley Park Plant
13430 North Black Canyon Highway
Phoenix, Arizona 85023

Glenn Culler
Computer Center
University of California, Santa Barbara
Santa Barbara, California 93107

Kenneth Davis
Department of Physics
Reed College
Portland, Oregon 97202

David Feign
University of California, Irvine
Irvine, California 95616

Wallace Feurzeig
Bolt Beranek and Newman
50 Moulton Street
Cambridge, Massachusetts 02138

Kenneth W. Ford
Physics Department
University of California, Irvine
Irvine, California 95616

Burton Fried
Department of Physics
University of California, Los Angeles
Los Angeles, California 90024

William J. Galloway
Bolt Beranek and Newman
Van Nuys, California

Ralph W. Gerard
University of California, Irvine
Irvine, California 95616

Richard B. Gooch
Control Data Corporation
8535 Florence Avenue
Dowdney, California 90240

Everett M. Hafner
Department of Physics
University of Rochester
Rochester, New York 14627

Frank Harris
Department of Chemistry
Stanford University
Palo Alto, California 94305

Robert Hulsizer
Department of Physics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

E. Leonard Jossem
Department of Physics
The Ohio State University
174 W. 18th Avenue
Columbus, Ohio 43210

John F. Kalbach
Burroughs Corporation
460 Sierra Madre Zilla
Pasadena, California 91107

James Kearns
Computer Center
University of California, Irvine
Irvine, California 95616

Andrew J. Kleinschmitz
Philco Corporation
3900 Welsh Road
Willow Grove, Pennsylvania

Edward D. Lambe
Department of Physics
State University of New York at Stony Brook
Stony Brook, New York 11790

William B. Lonergan
Radio Corporation of America
Electronic Data Processing Division
Building 204-2
Cherry Hill, New Jersey 08101

Arthur Luehrman
Department of Physics
Dartmouth College
Hanover, New Hampshire 03755

George Michael
Lawrence Radiation Laboratory
Livermore, California 94550

Thomas J. Padden
Philco Corporation
3900 Welsh Road
Willow Grove, Pennsylvania

Thomas R. Palfrey
Department of Physics
Purdue University
Lafayette, Indiana 47907

Joseph Rosenbaum
System Development Corporation
2500 Colorado Avenue
Santa Monica, California 90404

Noah Sherman
Department of Physics
The University of Michigan
Ann Arbor, Michigan 48104

Donald L. Shirer
Department of Physics
Valparaiso University
Valparaiso, Indiana 46383

Malcolm W. Strandberg
Department of Physics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Frederick Tonge
Computer Center
University of California, Irvine
Irvine, California 95616

Edward Turner
Physics Department
Washington and Lee University
Lexington, Virginia 24450

Richard Walther
Director of Research
Educational Sciences Division
U. S. Industries, Incorporated
Silver Springs, Maryland 20901

Karl L. Zinn
Center for Research on Learning and Teaching
The University of Michigan
1315 Hill Street
Ann Arbor, Michigan 48104

Commission on College Physics

Staff

John M. Fowler
Director

W. Thomas Joyner
Staff Physicist

Peter G. Roll
Staff Physicist

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appendix j

Flow Diagram: "Weightlessness"

by Arnold Arons

The fold-out pages which follow contain a complete flow diagram of a CAL drill-recitation unit on the subject of weightlessness. The unit was prepared on the COURSEWRITER system by Arnold B. Arons (Amherst College) at the Seattle Working Conference on New Instructional Materials in Physics (summer 1965). A brief description of the program can be found in Appendix C. It represents a first attempt at CAL programming by its author, and is presented here in flow diagram form not because it is a successful, useful, or tested example of CAL, but merely to indicate to the reader what can be accomplished in the COURSEWRITER system.

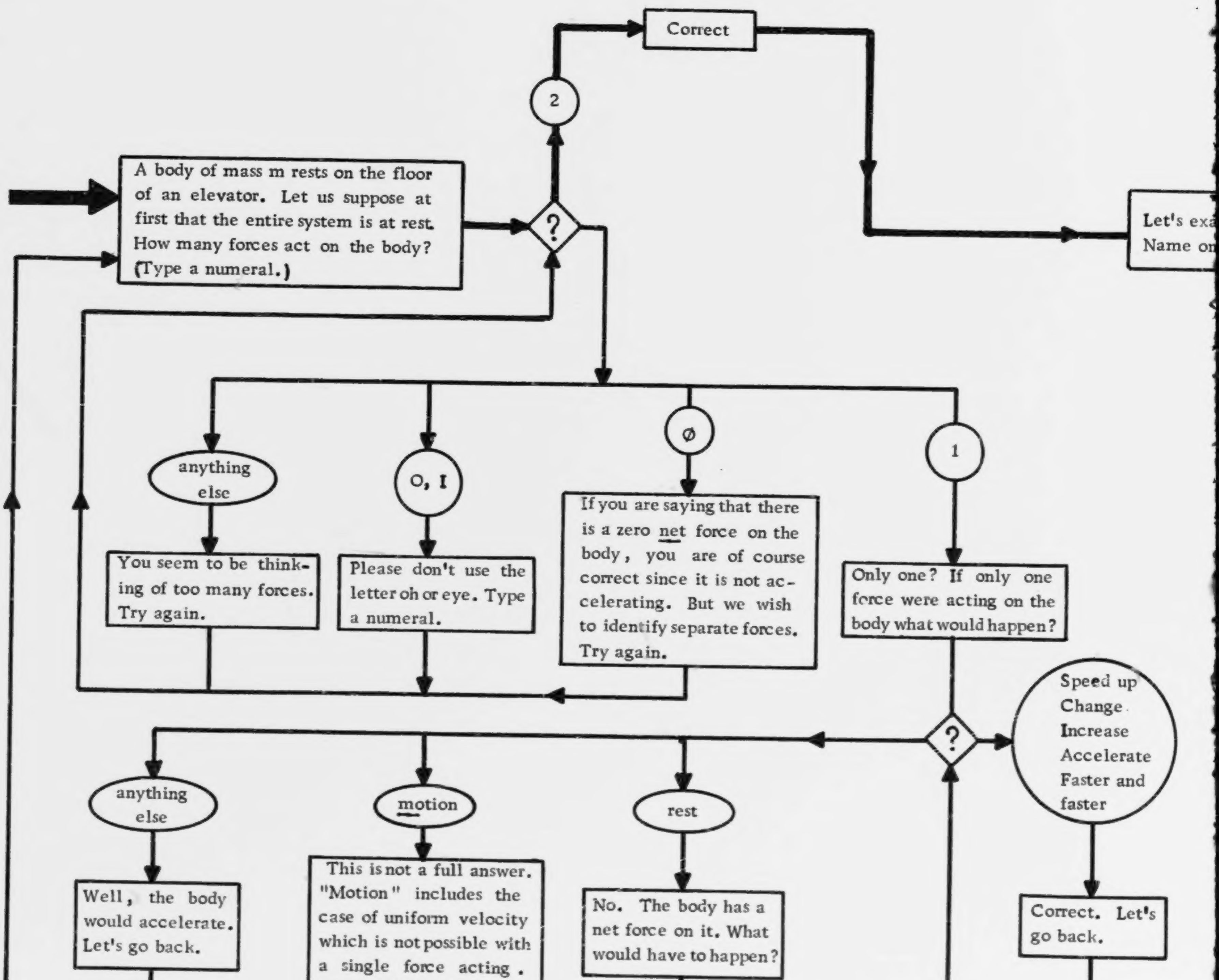
The following conventions have been adopted in designing the flow chart:

1. Text enclosed in rectangular boxes is presented to the student by the computer. It is typed out by the typewriter of the IBM 1050 instructional terminal.
2. Possible student responses are enclosed in circles or ovals. These responses are typed in by the student in answer to questions from the computer. The computer then compares the responses with those stored by the author in the computer, and, on the basis of a match or lack of match, selects a reply from its repertoire as indicated on the flow chart.
3. In seeking a match to a student response, the computer often looks for the group of letters underlined in the ovals, rather than for an entire word. E.g., the responses motion or mouse will be recognized as equivalent, on the basis of the underlined key letters mo. Some of the key letters and words have been underlined in the flow chart ovals; in other cases they have not because information on the keying was lacking.
4. The diamonds containing interrogation marks represent branch points in the program.
5. In general, the flow path corresponding to the recognized, "correct" answer to a question posed by the computer is found above the

branch point, while incomplete, unrecognizable, and incorrect answers are shown below the branch point on the flow chart. There are a few exceptions to this rule, necessitated by space considerations in laying out the chart.

6. A student who consistently gives the recognized correct answer to all questions posed by the computer will follow the path indicated on the flow diagram by the heavy lines.

SECTION 1


2
?
O, I
0
1
anything else
motion
rest
anything else
Speed up
Change
Increase
Accelerate
Faster and faster

A body of mass m rests on the floor of an elevator. Let us suppose at first that the entire system is at rest. How many forces act on the body? (Type a numeral.)

Correct

Let's exa
Name on

You seem to be thinking of too many forces. Try again.

Please don't use the letter oh or eye. Type a numeral.

If you are saying that there is a zero net force on the body, you are of course correct since it is not accelerating. But we wish to identify separate forces. Try again.

Only one? If only one force were acting on the body what would happen?

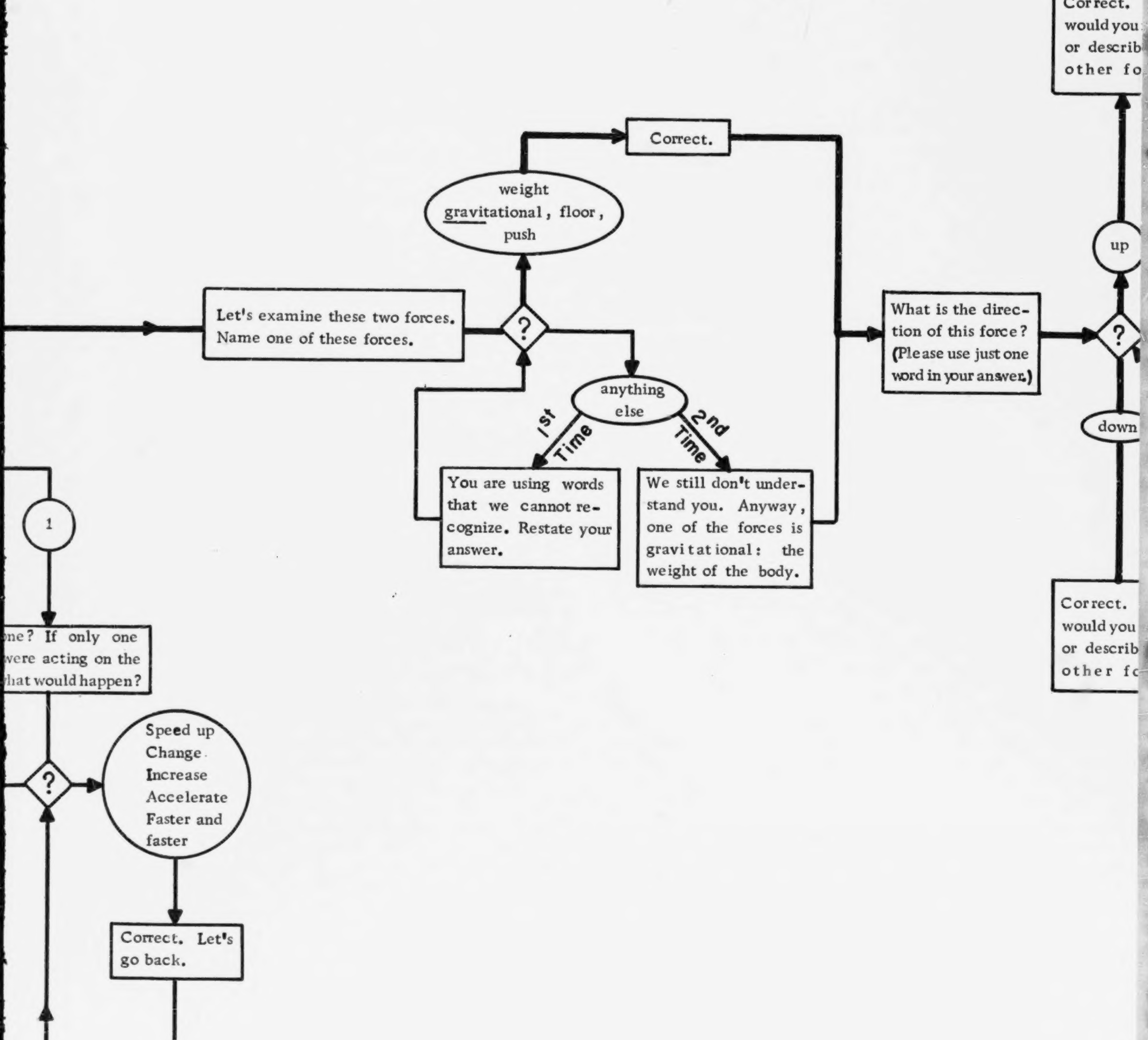
Well, the body would accelerate. Let's go back.

This is not a full answer. "Motion" includes the case of uniform velocity which is not possible with a single force acting. What would really happen to the body?

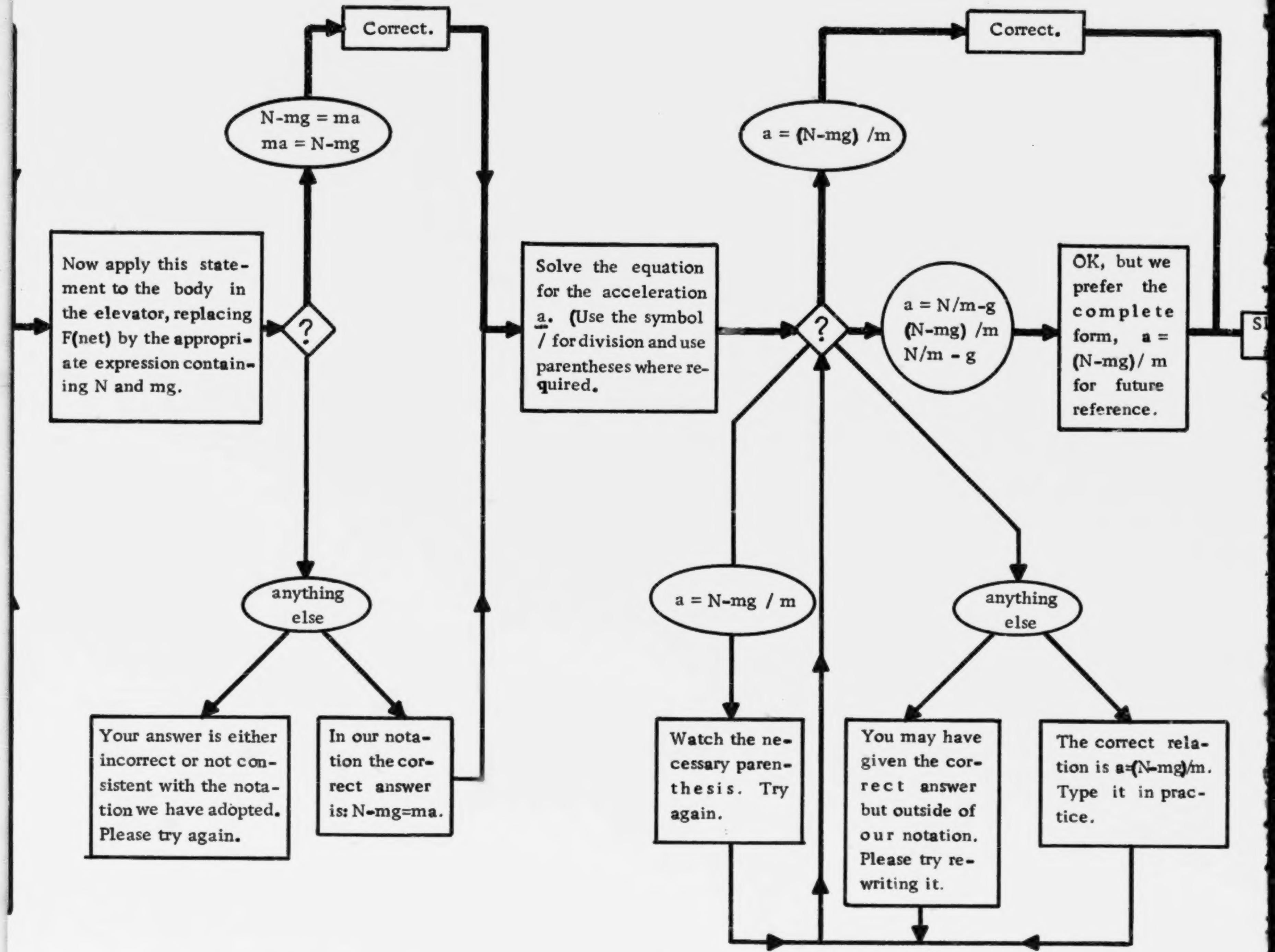
No. The body has a net force on it. What would have to happen?

Correct. Let's go back.

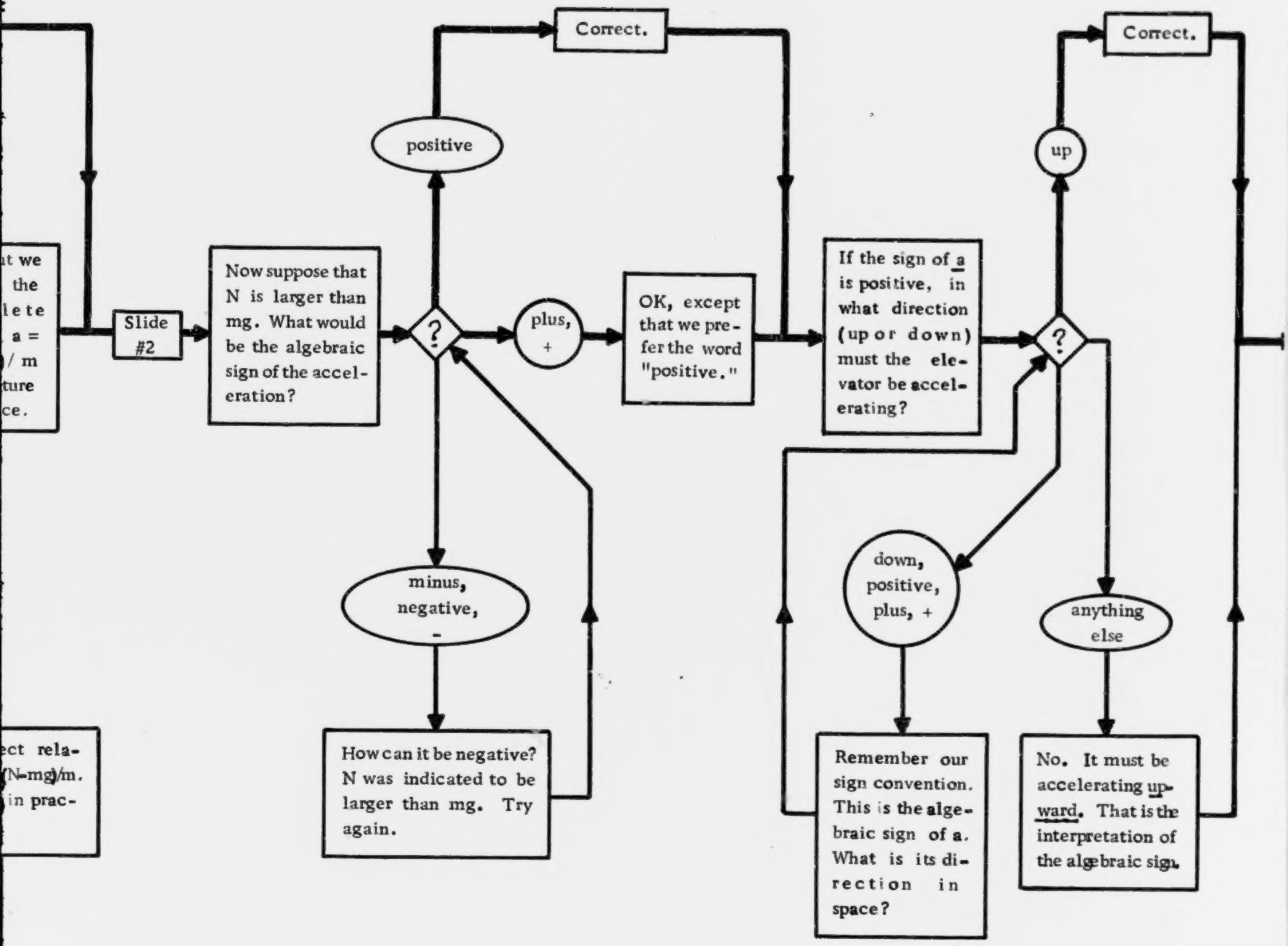
SECTION 2


Let's examine these two forces. Name one of these forces.
?
weight
gravitational, floor, push
Correct.
anything else
1st Time
2nd Time
You are using words that we cannot recognize. Restate your answer.
We still don't understand you. Anyway, one of the forces is gravitational: the weight of the body.
What is the direction of this force? (Please use just one word in your answer.)
?
up
down
Correct. would you or describ other fo
Correct. would you or describ other fo
1
ne? If only one vere acting on the hat would happen?
?
Speed up
Change
Increase
Accelerate
Faster and faster
Correct. Let's go back.

SECTION 1


Now apply this statement to the body in the elevator, replacing F(net) by the appropriate expression containing N and mg.
?
N-mg = ma
ma = N-mg
Correct.
anything else
Your answer is either incorrect or not consistent with the notation we have adopted. Please try again.
In our notation the correct answer is: N-mg=ma.
Solve the equation for the acceleration a. (Use the symbol / for division and use parentheses where required.
?
a = (N-mg) /m
Correct.
a = N/m-g
(N-mg) /m
N/m - g
OK, but we prefer the complete form, a = (N-mg)/ m for future reference.
S
a = N-mg / m
Watch the necessary parenthesis. Try again.
anything else
You may have given the correct answer but outside of our notation. Please try rewriting it.
The correct relation is a=(N-mg)/m. Type it in practice.

SECTION 2


t we
the
lete
a =
/ m
ture
ce.
ect rela-
(N-mg)/m.
in prac-
Slide #2
?
positive
Correct.
plus, +
minus, negative, -
?
up
Correct.
down, positive, plus, +
anything else

Now suppose that N is larger than mg. What would be the algebraic sign of the acceleration?

OK, except that we prefer the word "positive."

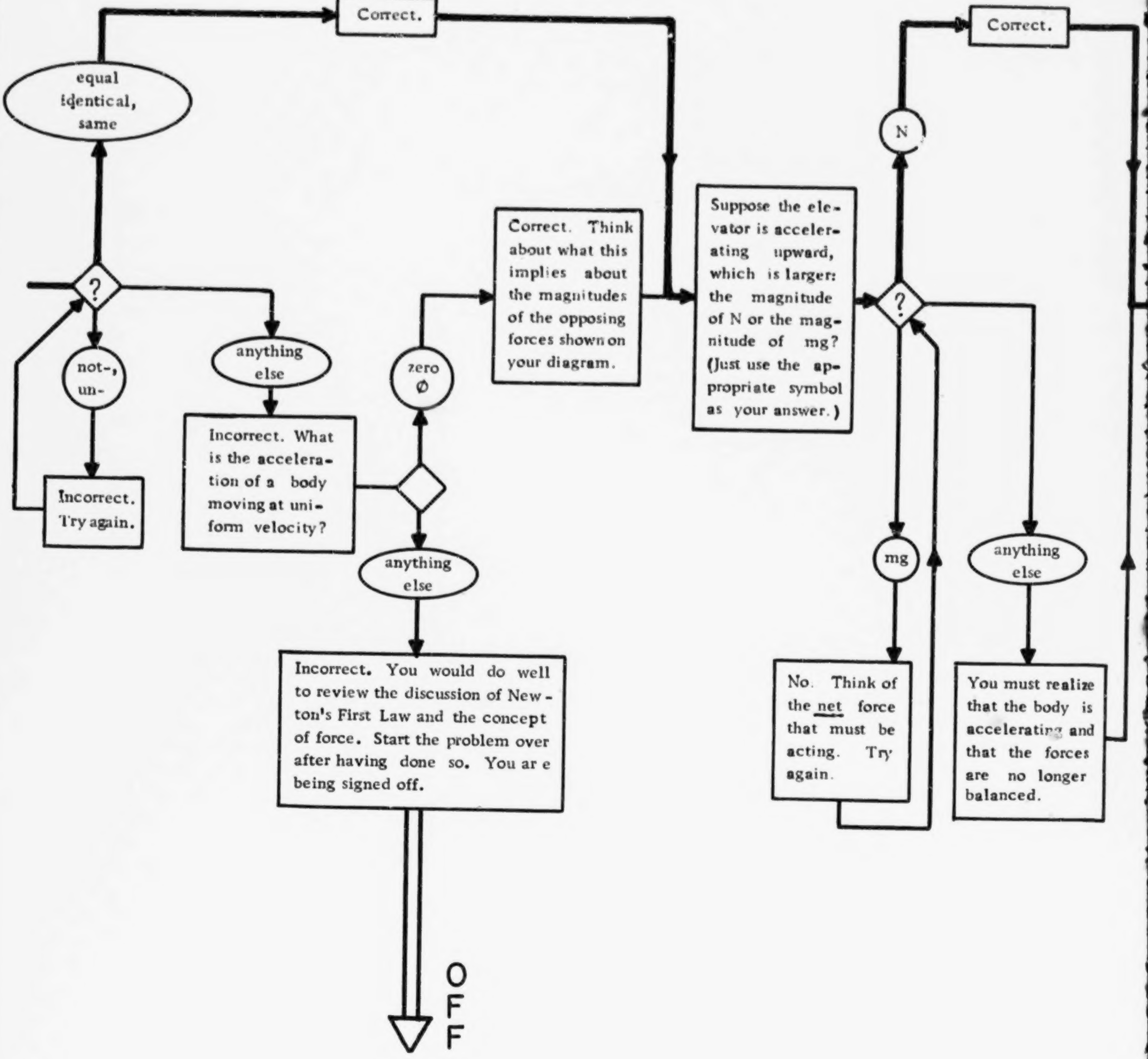
How can it be negative? N was indicated to be larger than mg. Try again.

If the sign of a is positive, in what direction (up or down) must the elevator be accelerating?

Remember our sign convention. This is the algebraic sign of a. What is its direction in space?

No. It must be accelerating upward. That is the interpretation of the algebraic sign.

SECTION 1


Correct.
equal
identical,
same
?
not-,
un-
anything
else
zero
∅
anything
else
N
?
mg
anything
else
Correct.
OFF

Incorrect. Try again.

Incorrect. What is the acceleration of a body moving at uniform velocity?

Correct. Think about what this implies about the magnitudes of the opposing forces shown on your diagram.

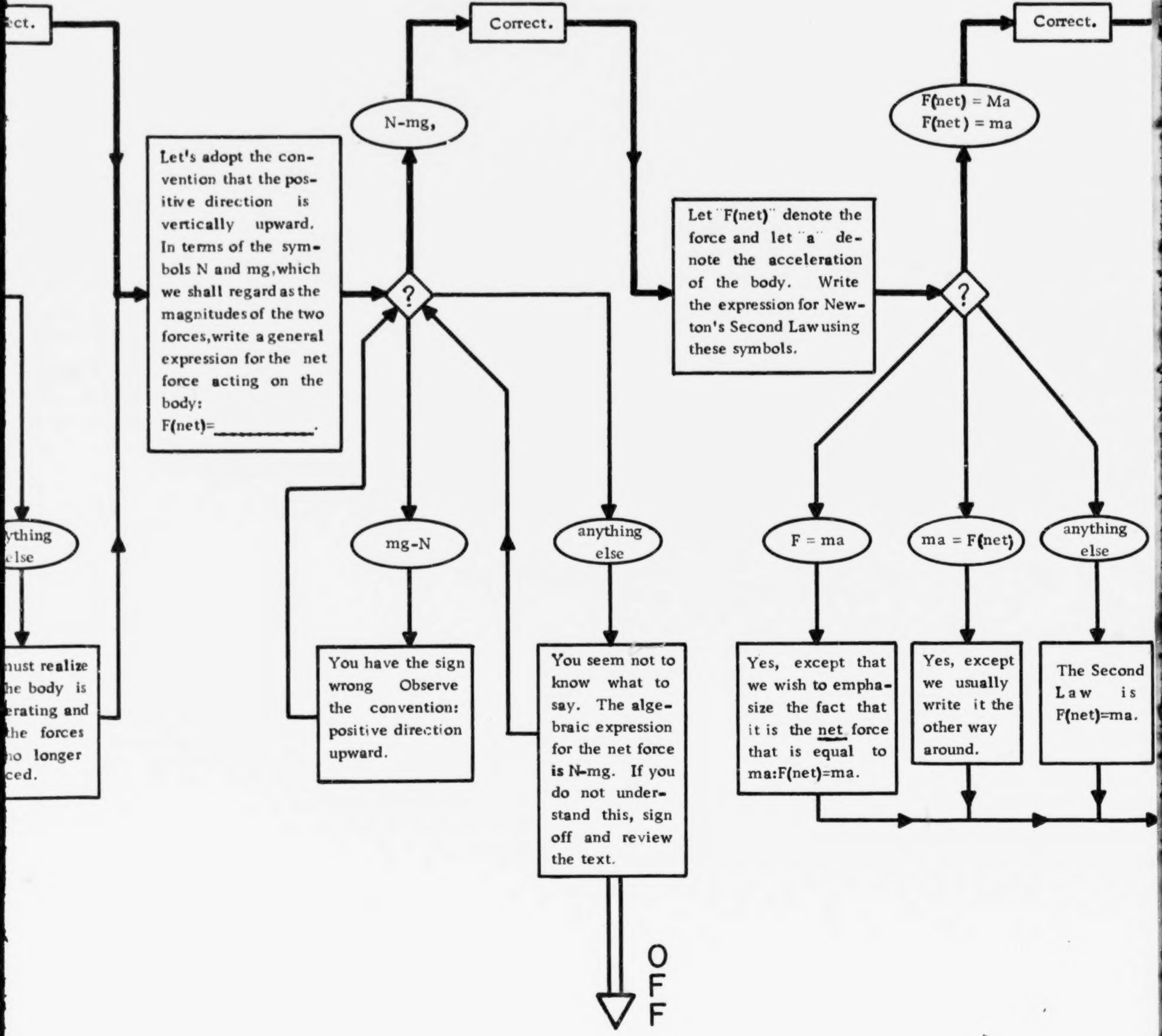
Incorrect. You would do well to review the discussion of Newton's First Law and the concept of force. Start the problem over after having done so. You are being signed off.

Suppose the elevator is accelerating upward, which is larger: the magnitude of N or the magnitude of mg? (Just use the appropriate symbol as your answer.)

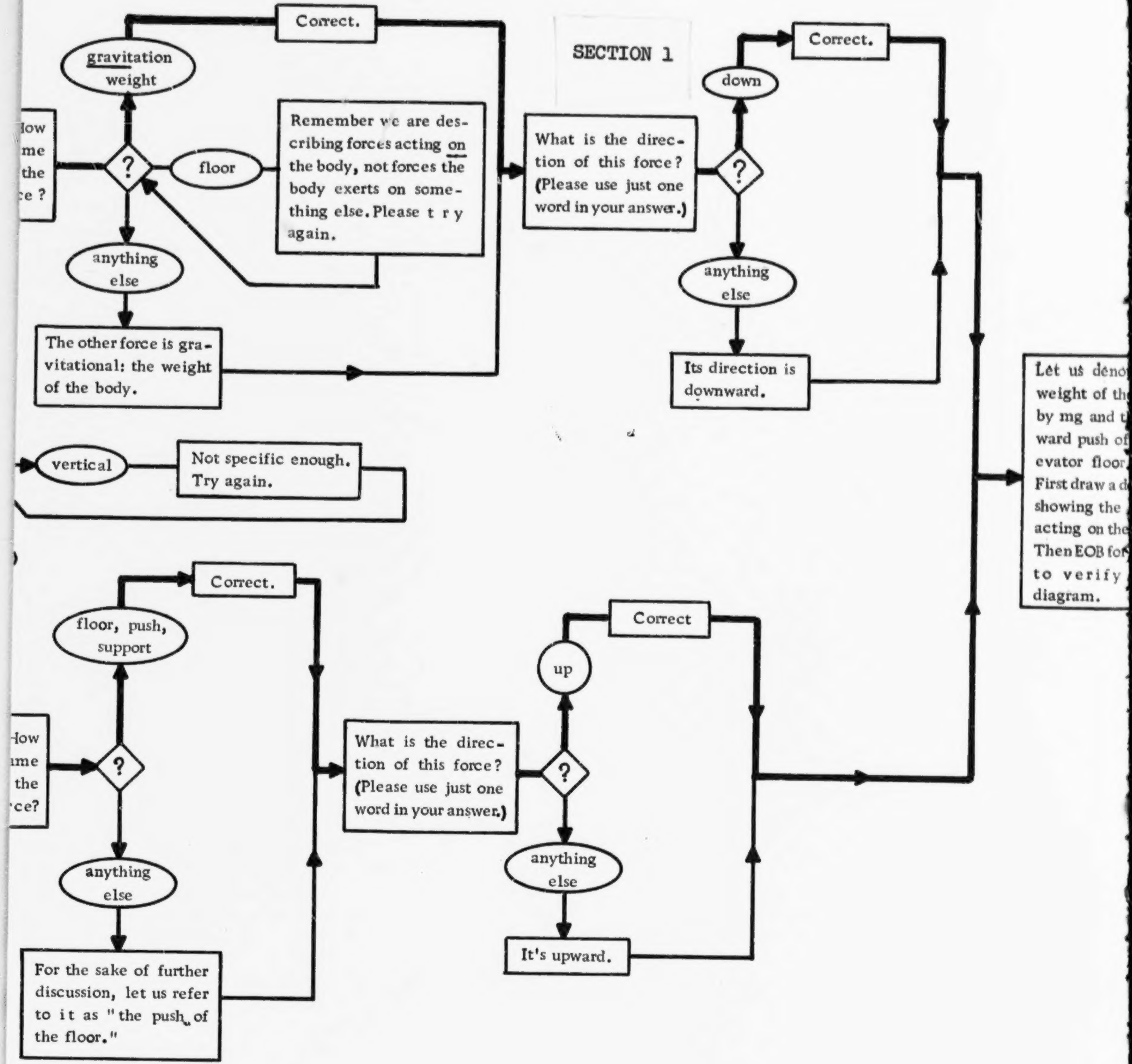
No. Think of the net force that must be acting. Try again.

You must realize that the body is accelerating and that the forces are no longer balanced.

SECTION 2


ect.
ything else
must realize he body is erating and the forces no longer ced.
Let's adopt the convention that the positive direction is vertically upward. In terms of the symbols N and mg, which we shall regard as the magnitudes of the two forces, write a general expression for the net force acting on the body: F(net)=___________.
?
N-mg,
Correct.
mg-N
You have the sign wrong Observe the convention: positive direction upward.
anything else
You seem not to know what to say. The algebraic expression for the net force is N-mg. If you do not understand this, sign off and review the text.
OFF
Let "F(net)" denote the force and let "a" denote the acceleration of the body. Write the expression for Newton's Second Law using these symbols.
?
F(net) = Ma
F(net) = ma
Correct.
F = ma
Yes, except that we wish to emphasize the fact that it is the net force that is equal to ma: F(net)=ma.
ma = F(net)
Yes, except we usually write it the other way around.
anything else
The Second Law is F(net)=ma.

SECTION 1


gravitation
weight
?
floor
anything else
vertical
down
?
anything else
floor, push, support
?
anything else
up
?
anything else

Correct.

Remember we are describing forces acting on the body, not forces the body exerts on something else. Please try again.

The other force is gravitational: the weight of the body.

Not specific enough. Try again.

What is the direction of this force? (Please use just one word in your answer.)

Its direction is downward.

Correct.

How
me
the
ce ?

Let us deno
weight of th
by mg and t
ward push of
evator floor.
First draw a d
showing the
acting on the
Then EOB for
to verify
diagram.

How
ame
the
rce?

Correct.

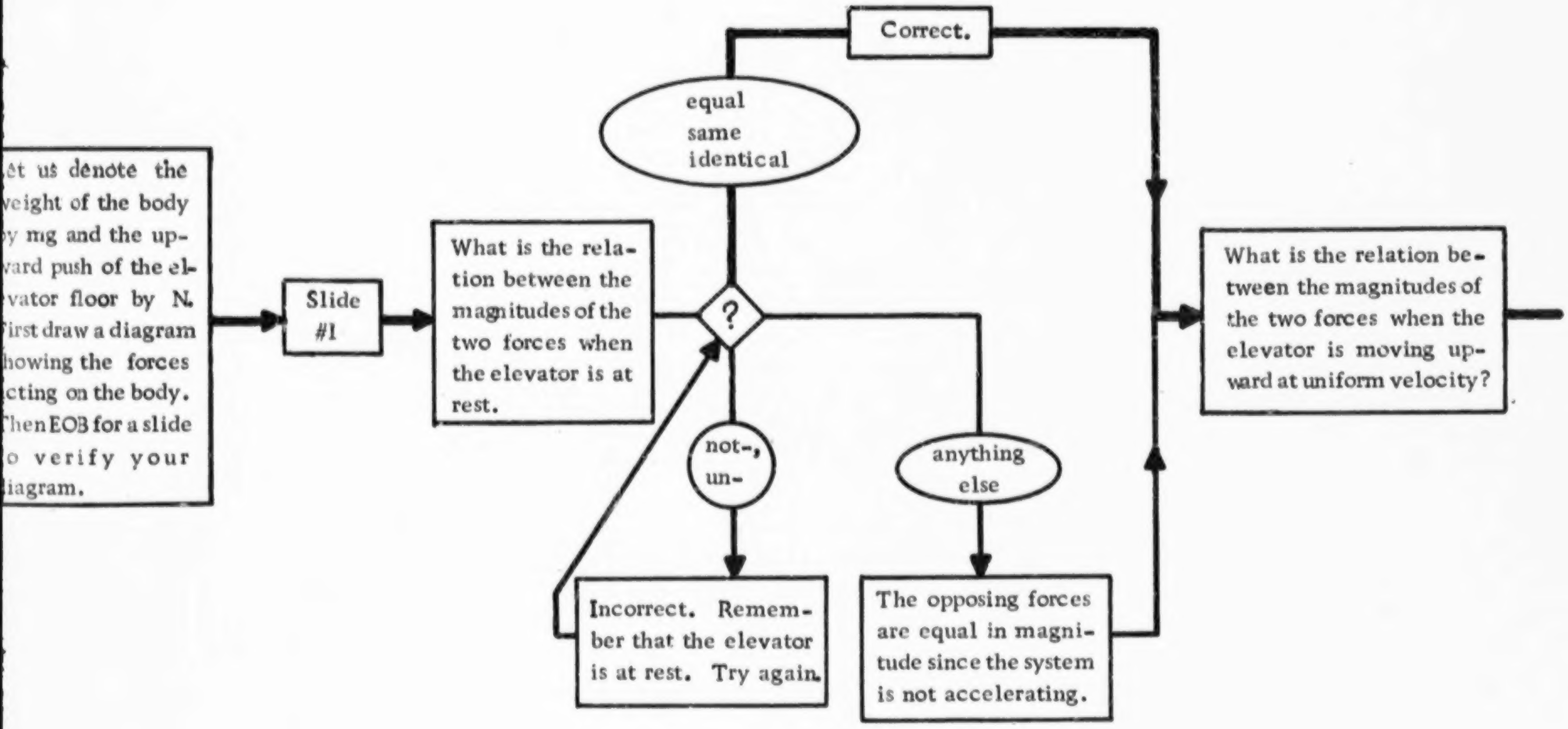
For the sake of further discussion, let us refer to it as "the push of the floor."

What is the direction of this force? (Please use just one word in your answer.)

Correct

It's upward.

SECTION 2



et us denote the
eight of the body
y mg and the up-
ard push of the el-
vator floor by N.
irst draw a diagram
howing the forces
cting on the body.
hen EOB for a slide
o verify your
iagram.

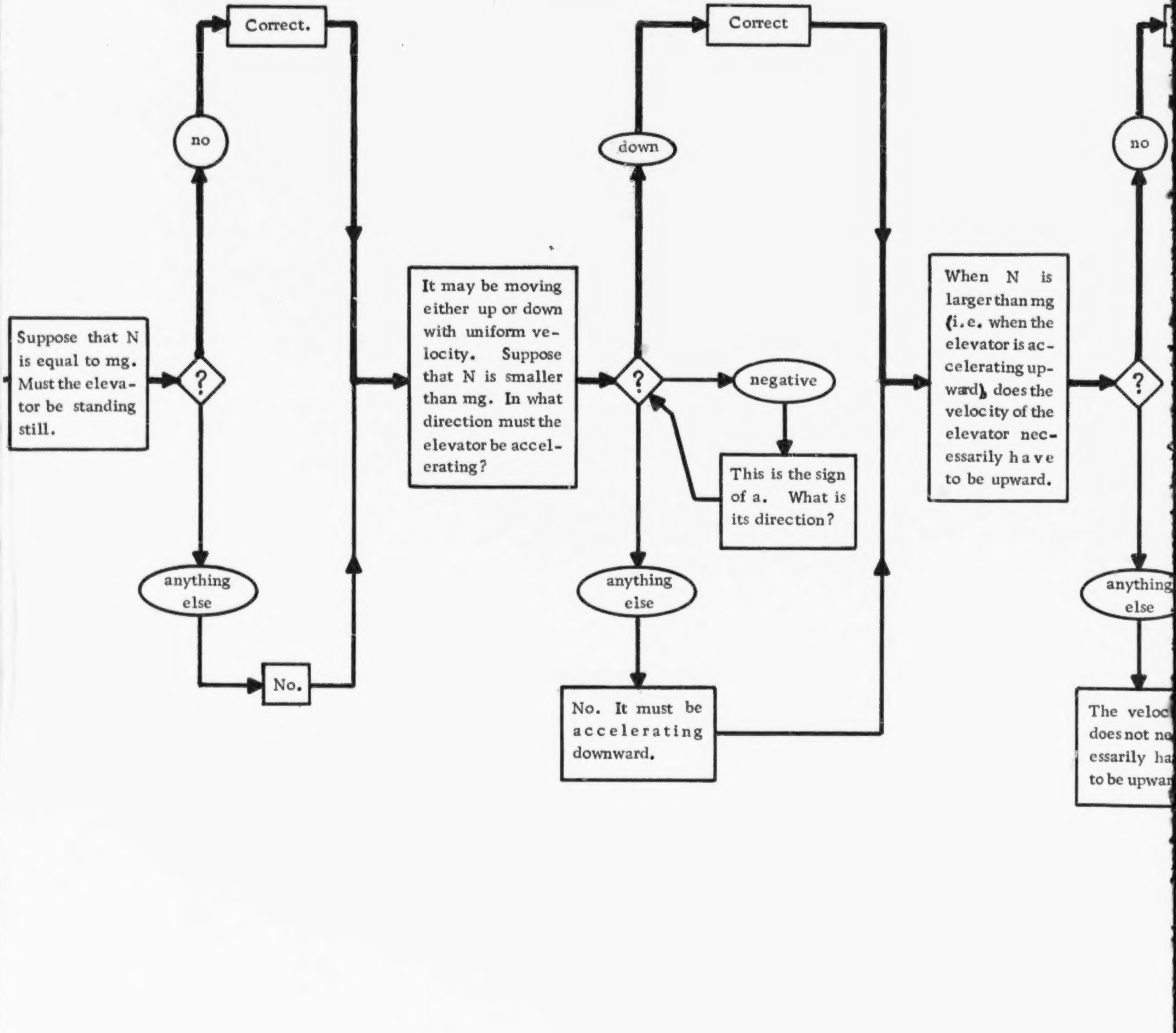
What is the relation between the magnitudes of the two forces when the elevator is at rest.

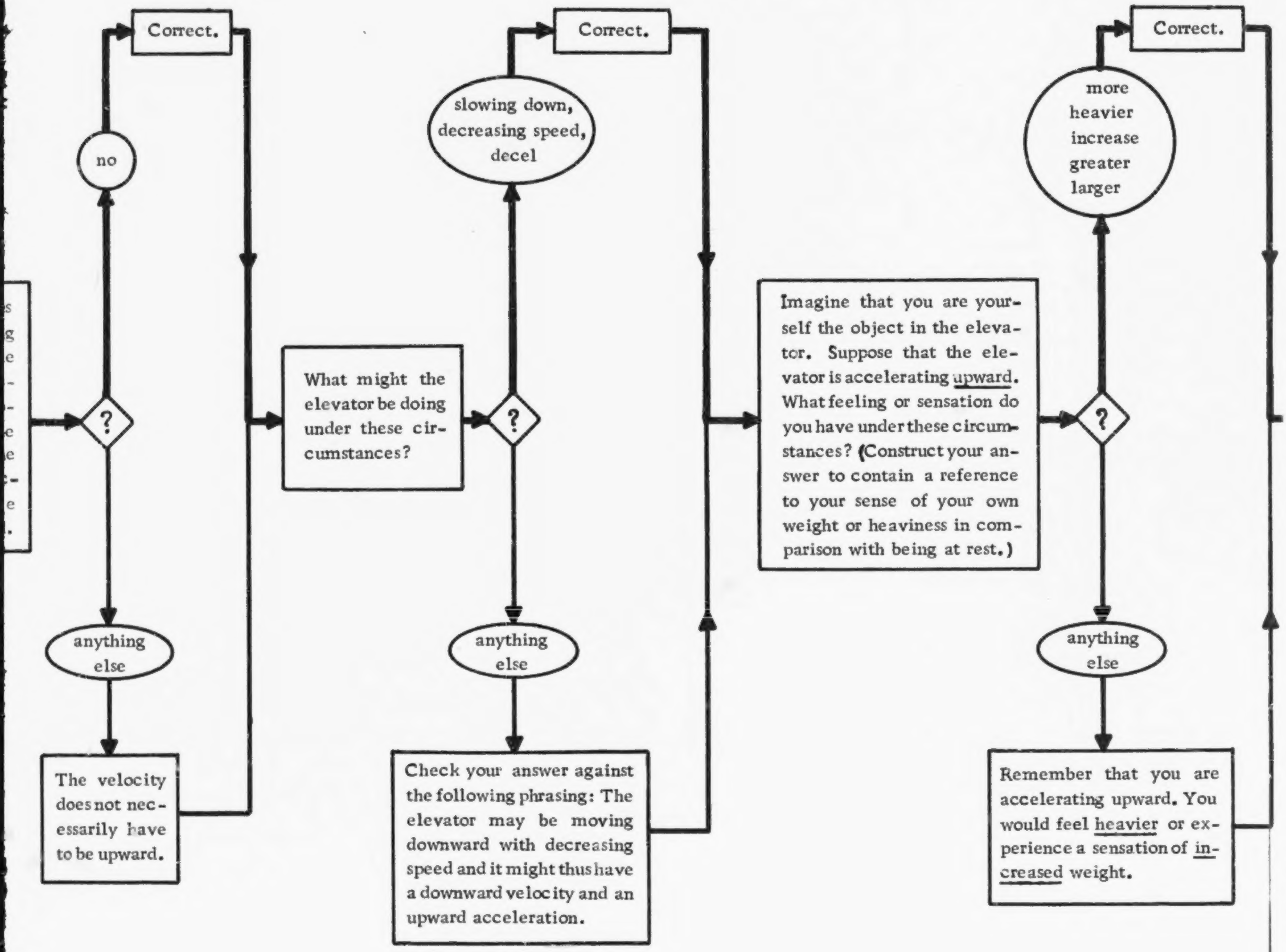
Incorrect. Remember that the elevator is at rest. Try again.

The opposing forces are equal in magnitude since the system is not accelerating.

What is the relation between the magnitudes of the two forces when the elevator is moving upward at uniform velocity?

SECTION 1


Suppose that N is equal to mg. Must the elevator be standing still.
?
no
Correct.
anything else
No.
It may be moving either up or down with uniform velocity. Suppose that N is smaller than mg. In what direction must the elevator be accelerating?
?
down
Correct
negative
This is the sign of a. What is its direction?
anything else
No. It must be accelerating downward.
When N is larger than mg (i.e. when the elevator is accelerating upward), does the velocity of the elevator necessarily have to be upward.
?
no
anything
else
The veloc
does not ne
essarily ha
to be upwar


?
no
Correct.
anything else
?
slowing down, decreasing speed, decel
Correct.
anything else
?
more
heavier
increase
greater
larger
Correct.
anything else

The velocity does not necessarily have to be upward.

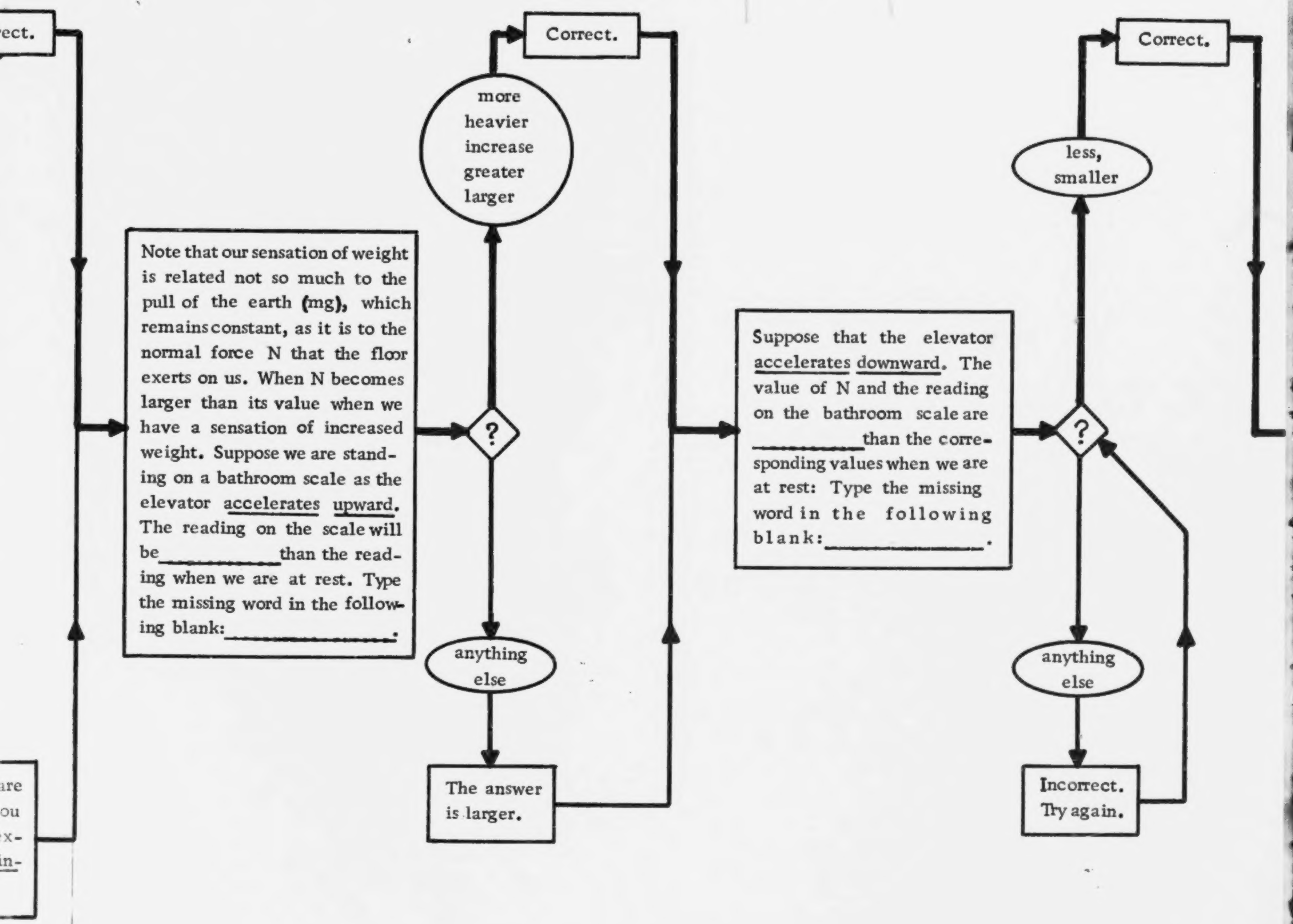
What might the elevator be doing under these circumstances?

Check your answer against the following phrasing: The elevator may be moving downward with decreasing speed and it might thus have a downward velocity and an upward acceleration.

Imagine that you are yourself the object in the elevator. Suppose that the elevator is accelerating upward. What feeling or sensation do you have under these circumstances? (Construct your answer to contain a reference to your sense of your own weight or heaviness in comparison with being at rest.)

Remember that you are accelerating upward. You would feel heavier or experience a sensation of increased weight.

SECTION 3



Note that our sensation of weight is related not so much to the pull of the earth (mg), which remains constant, as it is to the normal force N that the floor exerts on us. When N becomes larger than its value when we have a sensation of increased weight. Suppose we are standing on a bathroom scale as the elevator accelerates upward. The reading on the scale will be__________than the reading when we are at rest. Type the missing word in the following blank:__________.

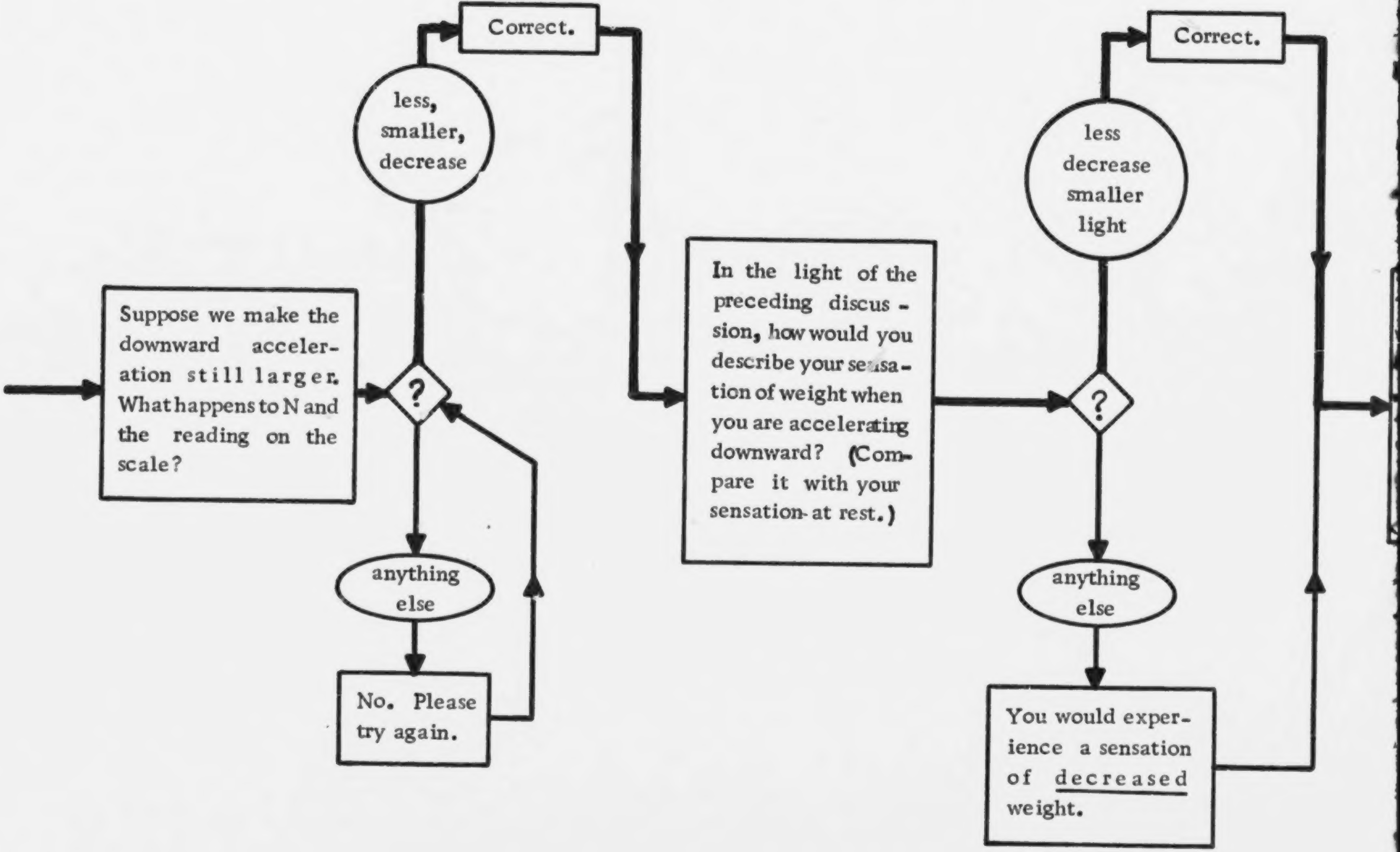
The answer is larger.

Suppose that the elevator accelerates downward. The value of N and the reading on the bathroom scale are __________than the corresponding values when we are at rest: Type the missing word in the following blank:__________.

Incorrect. Try again.

ect.
are
ou
ex-
in-
Correct.
?
more
heavier
increase
greater
larger
anything else
Correct.
?
less, smaller
anything else

SECTION 1



Suppose we make the downward acceleration still larger. What happens to N and the reading on the scale?

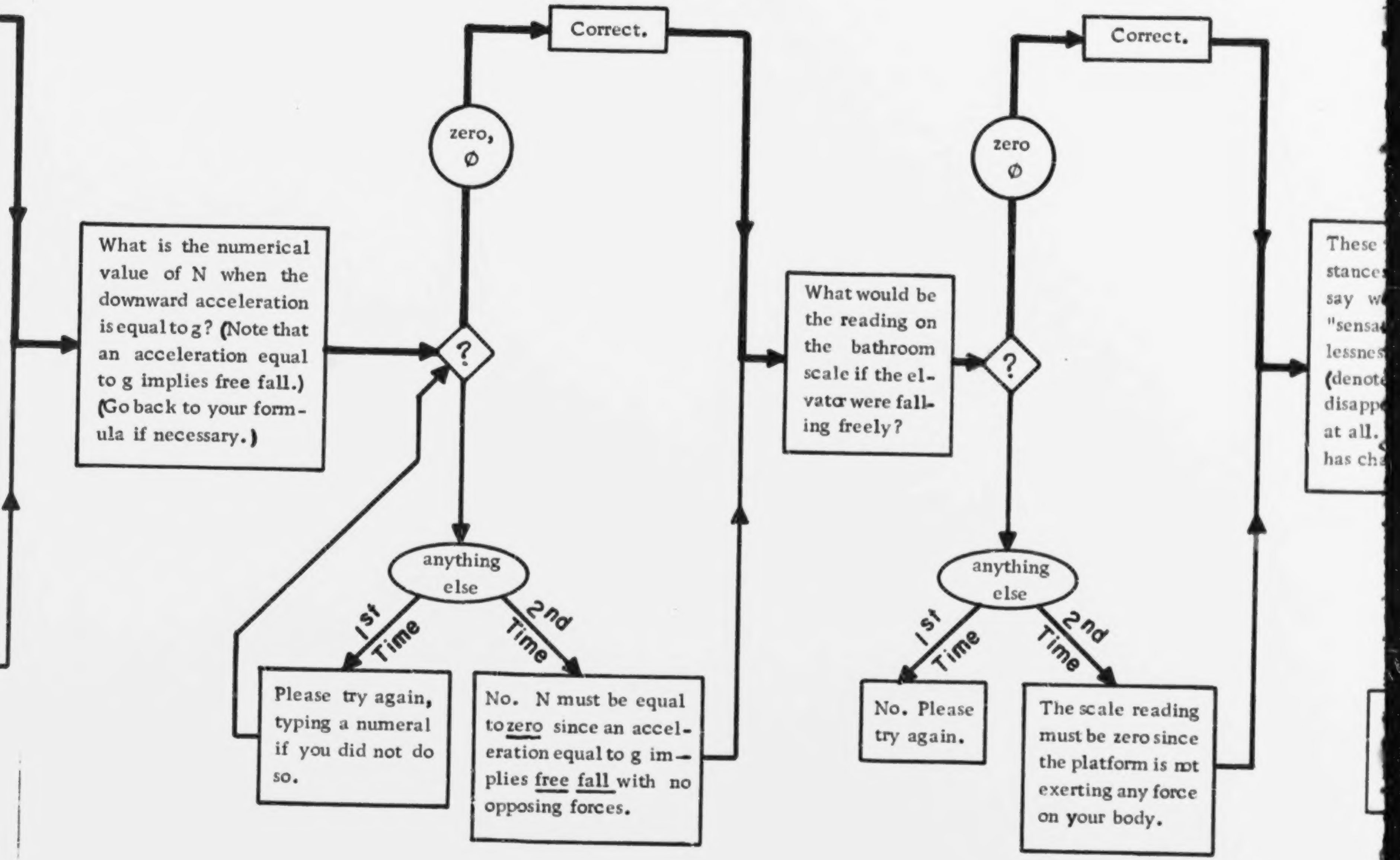
No. Please try again.

In the light of the preceding discussion, how would you describe your sensation of weight when you are accelerating downward? (Compare it with your sensation at rest.)

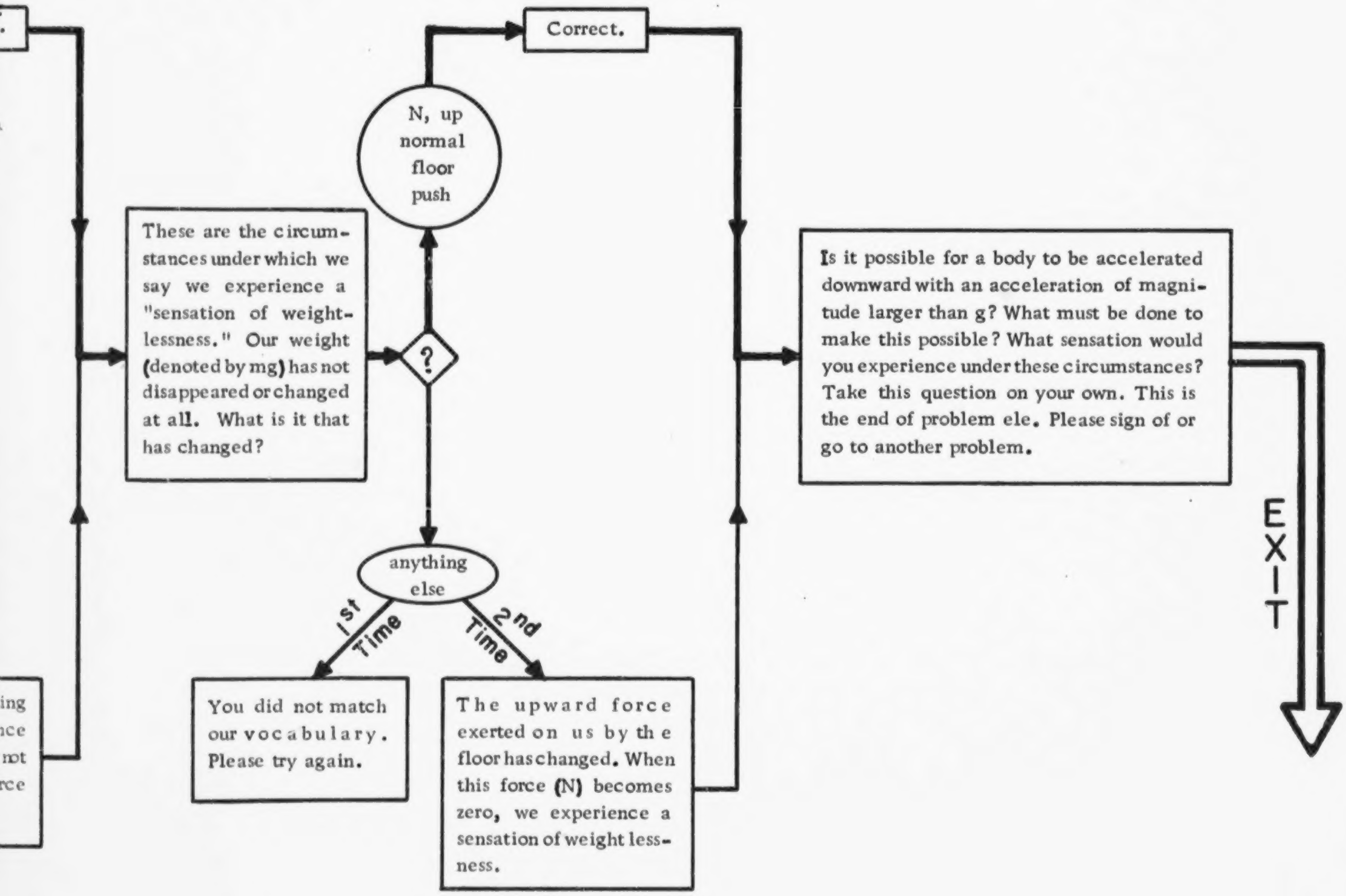
You would experience a sensation of decreased weight.

Correct.
less, smaller, decrease
?
anything else
Correct.
less decrease smaller light
?
anything else

SECTION 2


What is the numerical value of N when the downward acceleration is equal to g? (Note that an acceleration equal to g implies free fall.) (Go back to your formula if necessary.)
?
zero, Ø
Correct.
anything else
1st Time
2nd Time
Please try again, typing a numeral if you did not do so.
No. N must be equal to zero since an acceleration equal to g implies free fall with no opposing forces.
What would be the reading on the bathroom scale if the elvator were falling freely?
?
zero Ø
Correct.
anything else
1st Time
2nd Time
No. Please try again.
The scale reading must be zero since the platform is not exerting any force on your body.
These
stance
say w
"sensa
lessnes
(denot
disapp
at all.
has ch

SECTION 3



These are the circumstances under which we say we experience a "sensation of weightlessness." Our weight (denoted by mg) has not disappeared or changed at all. What is it that has changed?

You did not match our vocabulary. Please try again.

The upward force exerted on us by the floor has changed. When this force (N) becomes zero, we experience a sensation of weight lessness.

Is it possible for a body to be accelerated downward with an acceleration of magnitude larger than g? What must be done to make this possible? What sensation would you experience under these circumstances? Take this question on your own. This is the end of problem ele. Please sign of or go to another problem.

Correct.
N, up normal floor push
?
anything else
1st Time
2nd Time
EXIT
ing
nce
not
rce